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JOURNAL
AMERICAN WATER WORKS ASSOCIATION

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Meeting Major Emergencies in Water Supply

By L. M. Fisher, B. A. Poole, Arthur E. Gorman, H. H. Gerstein and Ralph E. Noble

A symposium presented on May 4, 1948, at the Annual Conference, Atlantic City, N.J., by L. M. Fisher, San Engr. Dir., U.S. Public Health Service, Washington, D.C.; B. A. Poole, State San. Engr., Indianapolis, Ind.; Arthur E. Gorman, San. Engr., Eng. Div., Atomic Energy Com., Washington, D.C.; H. H. Gerstein, Chief Filtration Chemist, Water Purif. Div., Dept. of Public Works, Chicago; and Ralph E. Noble, Prin. Filtration Bacteriologist, Water Purif. Div., Dept. of Public Works, Chicago.

The Place of Federal Agencies—*L. M. Fisher*

UNDER the present organization of the U.S. Public Health Service, the first step in meeting major emergencies is to secure whatever information is available on the nature and seriousness of the situation. In the past the principal sources, both official and unofficial, used by the Public Health Service have been the health department of the state in which the emergency existed, the governor's office, the Red Cross, army intelligence and the press.

The second step consists in ascertaining the amount of assistance needed. Sometimes this information can be obtained from the state health department by telephone, by a radio appeal or by having a Public Health Service representative visit the health department office.

After proper clearance has been received from the state authorities, contacts should be established with the local health department or such vestiges of it as may remain, and emergency measures should be promptly undertaken. When paralyzing emergencies overwhelm local health agencies, the state health authority should assume control. The Public Health Service should assist the state in restoring water services as promptly as possible. If the Public Health Service representative is the first health officer on the scene of the disaster, he should act in place of state or local health authorities and should take such steps as he can to save lives and property; but he should continue in temporary active charge only until state or local authorities can take over, unless they

designate him to remain in temporary charge.

This democratic procedure develops competence on the local level more promptly than any other way. Democracies survive only when citizens are capable of self-government. The ability of local groups of people to organize and deal with their troubles is one of the important reasons America has become great. No federal agency should take advantage of a disaster to supplant local authorities except temporarily, and then only if such action can be fully justified.

The Public Health Service official on the scene should promptly bring the resources of the federal government to the aid of the community, through state channels if possible or by direct action when necessary. To carry out his mission he must be supported by Public Health Service headquarters with men and materials.

Personnel

Men can be supplied either from the Public Health Service's own personnel on active duty, with regular, reserve or civil service status, or from the inactive reserve rolls. The inactive reserve officers, drawn principally from the staffs of state and local health departments, are willing to serve in emergencies and are available for call to active duty on short notice. The Public Health Service tries to keep on the inactive reserve list men who are specialists in the several categories of public health engineering—water plant operators, milk and food sanitarians, laboratory technicians, public health administrators and civil and sanitary engineers.

Materials

The Public Health Service maintains a limited number of mobile laboratories, which can in emergencies be sent to critical areas to make chemical and bacteriological examinations of water samples. It has a limited number of emergency chlorinators at various points throughout the country, as well as several mobile filter units. It does not maintain a stockpile of materials which may be drawn upon in emergencies, but endeavors to obtain priority for much needed essentials from government agencies controlling their allocation, or from manufacturers.

To deal with widespread major disasters involving several states, a national policy committee or board controlling funds and personnel is necessary. Such a committee was established, just below Cabinet level, to deal with the 1937 Ohio R. flood and included the heads of independent government agencies such as the PWA and the WPA.

Martial law, declared by state authority when local government organizations cease to function, may be necessary, making coordination between the health and the temporary military authorities essential. Martial law has not proved highly successful in the past in dealing with technical water supply and public health problems because of incomplete planning and inadequate personnel. In widespread war disasters which might occur in the future, however, the declaration of martial law in the affected area may prove necessary. In that event the military authorities should have definite plans to restore the water supply promptly and to provide adequate police and fire-fighting forces, which are even more important.

Planning and Organization

Any comprehensive program for meeting major emergencies due to military action must include a well-

thought-out scheme for a civilian defense organization. The civilian defense organization must be planned to save lives and property, maintain order and restore essential community facilities, such as communications, transportation and the water supply system, as promptly as possible. It should bring to the stricken water works the maximum amount of assistance possible in the shortest time. Details regarding the location of essential materials and plans for transporting them to the place where they are needed should be worked out.

Little or no experience in this country is available on dealing with major emergencies due to enemy action. The experiences of England, Germany and Japan can be of some help, however. The Civil Defense Board was established in November 1946 to make recommendations.

The basic concept in making plans to deal with major emergencies is self-help. Widespread destruction may occur in many municipalities and industrial areas simultaneously. A mutual aid program for supplying materials and assistance, such as was voluntarily organized in certain sections of the country by the Office of Civilian Defense during World War II, should again be organized, with improvements. It should be given authority by appropriate state and federal legislation, including the furnishing of directed mutual aid and the employment of mobile reserves adequate to deal with situations beyond the capabilities of municipalities or groups of municipalities.

The states should provide for giving aid quickly to municipalities when they have exhausted their capacity to help themselves, for directing mutual aid between communities, and for requesting federal assistance when necessity demands.

The federal government must provide guidance and coordination in planning, organizing, and training to meet water works emergencies. In major emergencies, widespread and serious damage to water works can be expected. Pumps, reservoirs, mains, large valves and filtration plants will all be in great demand, as well as skilled and competent personnel to make emergency repairs. Bearing in mind that *self-help* is the key to the problem, the federal government should direct only as may be necessary to insure uniform planning and action. It should employ mobile reserves, effect mutual-aid activities between states and, when required, assume control.

Full and authoritative information, recognition of the necessity for action, confidence in the efficiency of operation and ability to cope with the situation are all essential factors in the development of high public morale, and in inspiring public participation in remedial measures. Therefore, thorough discussion of plans with competent persons is necessary in advance so that when the plans need to be put into effect they will receive full support from the public.

Some of the more important problems that have to be solved are: (1) the establishment of reserve supplies of water works materials; (2) prompt repair and restoration of service; (3) the emergency evacuation of large numbers of civilians, together with the establishment of water supplies for refugee camps; (4) manpower requirements—skilled, semiskilled, technical and supervisory; and (5) the preparation of necessary legislation.

To deal adequately with the water works problems arising out of a ma-

jor emergency, such as atomic bombing, it is necessary that the problems be integrated with the whole civilian defense question. Legislation will be required. First, there must be action on the federal level setting up an appropriate national policy-forming body. Then there must be plans for a civilian defense agency to function on the federal, state and local levels. A nucleus of paid personnel must do the planning, and around it must be built a large voluntary organization of citizens upon whom will fall the great burden of carrying out the details of the plans. Not many volunteers can be expected until the actual threat of war impends.

The seriousness of major emergencies resulting from hostile acts staggers the imagination. Technical men should be stimulated to plan as meticulously as possible to deal with emergencies, but when complete planning is undertaken, one becomes overawed by the magnitude of the problem.

Under existing conditions there is no visible alternative to the heartbreaking task of planning rehabilitation measures following major war emergencies, but it should be apparent to all that it is imperative for the people of this country to unite with other nations throughout the world to prevent war, the greatest of all emergencies.

State and Local Responsibilities—*B. A. Poole*

Disasters are normally classified as natural—floods, cyclones, tidal waves and the like—or manmade—fires, spills or the havoc created by war. It is believed that practically all natural disasters will be handled at the state and local level. Once in a while, as in the 1937 Ohio R. flood, a natural disaster assumes national proportions. Even in that great catastrophe, and with admittedly incomplete plans, the affected area escaped epidemics, serious fires and suffering due to lack of drinking water.

Office of Civilian Defense planning helped a great deal to get the nation into position to cope with major emergencies, but the OCD organizations have disintegrated badly in many states. At present, however, it is doubtful that the states need any organization as comprehensive as they were. Obviously, every state should have a disaster committee or something similar, and it should be backed up with adequate authority. The state adjutant general, or his representative, should be in charge. There should be a state water coordinator—either the state sanitary engineer or someone from his office—who should occupy a staff position in the state emergency defense organization. He must *not* be in a subordinate position.

In the author's opinion, there is no justification for elaborate lists of mutual-aid equipment. Likewise, the practicability of maintaining on paper a large number of auxiliary crews is questionable. The state water coordinator should have a few key water works men to advise and assist him. His office should know where emergency equipment, supplies and men can be obtained on short notice and how these items are going to be paid for. Other agencies—both governmental and voluntary—interested in the over-all disaster program should be assured that water works personnel and the water coordinator will handle all water supply problems.

Large municipalities should have a scheme similar to the state plan. The water works superintendent, as well as the local health officer, should be on the local disaster committee.

The type of organization outlined above will be inadequate in the event of a great emergency such as war, but it will furnish the nucleus for a more elaborate organization. If there is another war, it is assumed that state and local authorities will be expected to handle civilian defense measures up to the time of actual invasion. It is doubtful whether martial law will be declared even if this country is under air attack.

Planning for the emergencies of war is not so simple as planning for natural disasters. If one could expect the type of warfare practiced in World War II—bombing, artillery fire and infantry attack—the kind of defense organizations recently laid on the table would suffice—at least in theory. The reservoirs of trained manpower in the state sanitary engineering departments, and particularly in the water departments, have been so badly depleted, however, that these organizations would fall apart under bombing of any consequence. In the last war the employees hired to replace those who went into the armed forces and the defense industries, and the auxiliary crews, lacked the experience necessary to stand up under pressure. The solution to the personnel problem is to keep more trained manpower at home. In the author's opinion, this cannot be done without a universal manpower act. It might be possible to exempt men from military service but a $1.25-an-hour man cannot be prevented from taking a $2.25-an-hour job without a national program which tells each man where his spot is.

Need for Information

There is every reason to believe that the next war will not be like the last one. America has the atom bomb, and others will have it, if they do not already. If such weapons as radioactive mists and biological agents are available to an enemy, they will certainly be used on this country before invasion by foot soldiers. The acceptance of the author's earlier premise that state and local authorities will handle civilian defense up to the time of invasion implies the necessity of planning in advance. Likewise, it will undoubtedly be agreed that planning is impossible without adequate information.

It should be remembered that just as great an emergency in water supply can result from everyday operations in this country as from enemy action. In the author's opinion, the day-to-day operations of the next few years will create more imminent danger than the possibility of war. Imagine the catastrophe which could result if some of the so-called "hot stuff" created by atomic fission entered the headwaters of one of the nation's major river systems! At the recent Conference of State Sanitary Engineers, the discussions indicated that the state authorities at least are greatly concerned and feel it is high time that a little information was made available.

It is obvious that secrecy is required in the production of nuclear energy and also in the development of biological warfare. On the other hand, the welfare of the people is also important. There seems to be no reason why security cannot be maintained by

taking a small group of U.S. Public Health Service officers and making them a liaison unit between the water works field and those agencies engaged in the development of atomic energy and biological warfare. The members of this liaison unit should be told all that is known. They should also be permitted to take a few responsible officials of each state into their confidence sufficiently to permit the preparation of a state disaster plan geared to the peculiarities of the state involved. Following the preparation of the plan, the members of the U.S.P.H.S. liaison group should consider it one of their primary responsibilities to see that the plan is revised as often as new developments require it.

Atomic Energy and War Emergencies—*Arthur E. Gorman*

Water is a basic resource for which there is no substitute. It is a *must item* in peace or war. Any situation which unfavorably affects the quality or reduces the available supply of water to a community or to industry strikes at an indispensable service—one which involves public health and safety and is a basic factor in the national economy.

In the event of war in the near future, American water works officials would be faced with some serious problems. Most citizens recognize the importance of water supply for domestic uses and for fire protection. They are willing to pay any reasonable charge for this service as a family and community operating expense. Few realize, however, that to be assured of water service during a period of emergency requires skillful advance planning and the installation of stand-by facilities which may be quite costly. A very few indeed know that the nation's war potential is directly related to its ability to supply water to cities, war industries, port and transportation facilities, and training camps.

Water and War Production

Experience during the last war revealed how dependent some of the basic war production plants were on water supply and what desperate efforts often had to be made to prevent a breakdown in operations at essential plants where water service was not reliable. If a nationwide drought had occurred during the war, the production program would have been dealt a solar plexus blow, the effect of which might have been very costly in lives of American troops. Considering the current world situation, a realistic program of national security should include an early appraisal of all utility facilities and the development of a policy for reinforcing weak points and expanding plants where additional military requirements are indicated. This implies an increase in the basic productive capacity of industries serving utilities.

The great war industries, such as those producing explosives, gasoline, rubber, steel, copper and aluminum, and those manufacturing military equipment by using these basic commodities, are definitely dependent on water for processing methods, boiler feed, heat exchange and a variety of other industrial uses. Officials of water utilities which serve these industries should be kept informed of anticipated changes in water demands, whether they represent normal growth or sudden expan-

sion to meet war requirements. Utility plant extensions should be planned accordingly.

In new war plants for which it is expected that a private water system will be developed, the advice of consultants on the availability of supply should be sought well in advance of site selection. This is particularly true for ground water developments, because there are many critical areas where the supply of ground water for additional use is definitely limited.

Limitations on the supply and availability of materials during and since World War II, coupled with the sharp rise in demand for water to serve new houses and the expansion of industrial facilities, have left water, as well as other utilities, short of reserve capacity. As a result, the water industry is now not as well prepared to meet sharp increases in demand for war production as it was at the outbreak of the last war. The twelve to eighteen months' backlog in unfilled orders for cast-iron pipe—one of the most important construction materials in a water utility system—is an example.

Protection of Public Supplies

In time of war or any other national emergency, extraordinary precautions must be taken to protect public water supplies. This calls for a special kind of advance planning, based on a realistic appraisal of the potential hazards involved and the degree of risk which can or cannot be taken in any particular area. Technological developments have outmoded many facilities and procedures which were accepted as standard in the late war. Thinking and planning must be revised accordingly.

Utility engineers and operators must meet with specialists in military planning, both offensive and defensive. A frank exchange of information, subject to reasonable security regulations, and the development of a mutual cooperative program will do much to avoid the difficulties and confusion which were common during the last war. There is no longer a necessity for the sharp separation of civilian and military functions which may have had some justification when civilians were not exposed to active warfare and when there was a gradual drift from armed peace to open hostilities. It is conceivable that in the next war enemy action may affect civilians and industry well in advance of its impact on any considerable number of the military forces. A system under which there would be more blending of military and civilian responsibilities is, therefore, very desirable, especially in the highly technical utility field, in which competition for manpower is keen and the prompt and effective repair of damage is essential in the public interest.

For public health reasons, it is necessary that extraordinary precautions be taken to prevent accidental or planned contamination of public water supplies in future wars. Although the saboteur has not been very effective in the past, he may be a serious factor in future conflict. It is well known that vital units of some of the most important water utilities are vulnerable to destruction by skilled saboteurs. Accidents, such as spills or explosions from hazardous industries, which might result in the contamination of public water supplies, can and should be minimized by the proper location of such plants and efficient control over their operations. Supplementing these precautions, a plan should be developed for emergency

action at the plant and in any surrounding area likely to be affected if the worst should happen.

The possibility of damage to essential utilities by enemy action should be appraised, and such reinforcement of plant should be made as is practical under the circumstances or is indicated as necessary because of the value of the particular utility to the national security. This is also a nice problem of cooperation between water works and public health officials and the military.

Atomic Energy Plant Wastes

One of the great new industrial production and research developments since the last war is in the field of atomic energy. Atomic energy plants are operated under the supervision and control of the Atomic Energy Commission. As in most industries, their operations result in waste products which must be disposed of. These wastes are radioactive in various degrees and for different periods of time, ranging from seconds to thousands of years. Some of the wastes are highly toxic and are of such character that their disposal into the air, to the soil or into watercourses without proper pretreatment would constitute a public health hazard. The Atomic Energy Commission and its contract operators are well aware of their unique responsibilities in the development of this industry and are devoting much time and money to seeking adequate and economical solutions of various waste disposal problems.

Development of Techniques

Even though the contaminating materials may be entirely different, the problems of waste disposal, water supply and environmental sanitation encountered in atomic energy operations parallel those experienced at industrial plants and in organized communities. Just as the water bacteriologist seeks to determine the kinds and amounts of bacteria in water, a health physicist in an atomic energy plant or laboratory may use a Geiger counter and other instruments to determine the character and power of rays emanating from the disintegration of radioactive material. Water works engineers, chemists and bacteriologists are trained to give special consideration to many environmental factors which may affect, directly or indirectly, their supply, plant facilities and treatment processes. They follow time-tested and generally accepted operating practices and analytical techniques. They are guided in decisions by standards or tolerance limits which have found general acceptance because they rest on a foundation of widespread research and chemical and epidemiological evidence—all supported by a long record of biostatistics.

In the field of atomic energy, the backlog of experience is limited. There are endless problems to solve and new areas to be explored. Nevertheless, work is under way to develop similar tools, techniques, standards and tolerances dealing with radioactivity which will find wide acceptance by all. Initially the prime concern was with employee protection in plants and laboratories where nuclear fission processes or research was carried out. A great deal more has to be done in developing standards and tolerances which will meet general acceptance.

Those who may wonder what is being done to safeguard surface or underground sources of public water

supplies against contamination by radioactive and toxic wastes from atomic energy plants will be most favorably impressed when the facts are made known. The effect of radioactive wastes on various biological processes of special interest to sanitary engineers is under observation and very shortly will be a subject of extensive research. It is the commission's objective to avoid for this new industry and the public some of the serious mistakes and resulting problems which too often in the past rose to plague other new industries, at times causing serious damage to life and property in near-by areas.

Training of Technicians

The need for widespread dissemination of knowledge about radioactive products and their properties, methods of safe handling in storage and distribution, and means of detecting their presence in small quantities and of ascertaining their significance under various circumstances is fully recognized by the commission. The help and advice of national professional societies in distributing released information to their members will be appreciated. At the same time, assistance will be needed in training qualified engineers, chemists, bacteriologists, sanitarians, inspectors and operators in those aspects of problems peculiar to atomic energy operations which are of special concern to water works and public health officials.

It is obvious that in a national emergency the now limited knowledge of precautions to be taken to protect the public against the hazards of radioactive materials must be extended. The training of water works and sanitary engineering students in the basic principles of nuclear physics, and the application of new developments in atomic energy to their field of interest, is a most important responsibility of the industry, the schools and colleges, and the Atomic Energy Commission.

Possible Effects of Chemical and Biological Warfare—

H. H. Gerstein and Ralph E. Noble

Discounting apparently fantastic statements in the press regarding the extreme effectiveness of the chemical and biological warfare agents, one cannot escape the conclusion that their potentialities for the destruction and devastation of life and property must not be ignored. Those responsible for the safety and protection of water supplies must give serious consideration to the possible effects of, and safeguards against, these new agents if they are used deliberately for the purpose of contaminating public water supplies. At the outset, it is desired to state that little information was found on the subject of specific value to the water works man.

In a general way, chemical warfare involves the use in war of synthetic chemicals in the form of gases and poisons; whereas biological warfare employs pathogenic bacteria, fungi, viruses, protozoa, rickettsias and toxic agents derived from living organisms, to kill or incapacitate human beings, domestic animals or food crops. Such warfare may be directed against military or naval forces, civilian populations, livestock or crops (1).

The basic source of published information on bacterial warfare is a

report released about a year ago which contains a critical analysis of the possible military applications of the available bacterial agents and the means of protection against them. This study was made in 1942 under the auspices of the National Research Council by Rosebury, Kabat and Boldt (2).

Biological Agents

In the preliminary analysis of potential bacterial warfare agents, Rosebury and his associates considered the various disease-producing bacteria and their products transmissible by water-, air- and vector-borne routes of infection. Although water-borne agents offered less promise than air-borne, it was pointed out that the use in water supplies of botulinus toxin and leptospira causing Weil's disease merited further study. It was suggested that the high infectivity of psittacosis virus gave much promise for use as an air-borne agent. Melioidosis and tularemia pathogens were also considered as possible air-borne agents of high infectivity and fatality.

As yet, none of the bacterial agents are known to have been used in a military operation. Their effectiveness is a matter of speculation, but their potentialities cannot be discounted. It is reported that methods have been developed for the mass production of crystalline botulinus toxin, and that 1 gram of this product represents 7,000,000 lethal doses (3). Based on these data, it is calculated that 1,000 lb. of botulinus toxin, evenly dispersed in a water supply, would contaminate approximately 42 bil.gal. to the extent that drinking 50 ml. of the water would provide a lethal dose.

It is also stated that 1 ml. of an unpurified preparation of psittacosis virus contains approximately 20,000,000 respiratory doses for man. Even with a 0.01 per cent dissemination efficiency of the air-borne virus, the potency of such an agent would be extremely high (3).

It is considered possible that the virulence of known pathogenic microorganisms may be enhanced so greatly as to make known methods of protection ineffective against them (1). On the other hand, it is also possible that some of the biological agents, because of the rapid deterioration of infectivity and toxicity on release, may not cause as serious contamination of water supplies as might be expected. It is, however, logical to assume that the agents chosen for an attack on water supplies would be those whose toxicity and pathogenicity will not be affected by the ordinary purification treatments.

Although atomic bomb production requires enormous industrial capacity and technical ability, at present believed available only in the United States, the development of biological warfare agents is feasible with a limited industrial capacity and without vast expenditures of money or the construction of huge production plants. It is therefore well within the realm of possibility for economically inferior nations to develop and mass-produce extremely potent biological warfare agents which could be effectively used against more powerful nations. Warning of an attack cannot be guaranteed (1).

Release of Information

It is realized that the material presented in this paper is inadequate and of a general nature. The conclusion cannot be escaped, however, that water resources are vulnerable to most se-

rious damage if deliberately attacked with the new chemical and biological weapons. Because there are possibilities that these agents can be used for an attack, without warning, it is believed that the National Security Council should consider making available to those responsible for the operation of water works, or to key men in the water works profession, information regarding efficient defense measures for structural protection and purification treatment of water supplies. In that way effective planning and preparations can be instituted prior to the occurrence of a national emergency. If such information has not as yet been developed, it is urged that the National Security Council take immediate steps to carry out studies for the development of effective methods of protecting water resources against attack by the agents of modern warfare. The results of these studies should be released to the water works profession under whatever security safeguards may be required.

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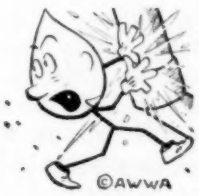

Artificial Recharge of Ground Water Reservoirs

By A. Nelson Sayre and V. T. Stringfield

A paper presented on May 4, 1948, at the Annual Conference, Atlantic City, N.J., by A. Nelson Sayre, Geologist in Charge, Div. of Ground Water, Water Resources Branch, U.S. Geological Survey, Washington, D.C., and V. T. Stringfield, Sr. Geologist, Div. of Ground Water, Water Resources Branch, U.S. Geological Survey, Washington, D.C.

IN the past water supplies were drawn largely from surface water sources. The development of ground water lagged for a variety of reasons. O. E. Meinzer (1) states that "at the beginning of this century there were only a few areas in this country in which large quantities of ground water were pumped from wells." Since that time, the improvement of well construction methods, the introduction of cheap power and superior pumping equipment, together with certain advantages which ground water provides, have combined to increase the use of ground water in nearly all parts of the United States. In the past decade the rate of use has been greatly accelerated. In 1945, according to a survey made by W. F. Guyton (2), an average of about 20 bil.gal. of ground water a day was being used—nearly double the use in 1935.

In the Memphis area, the total pumpage of ground water in 1928 was about 39 mgd.; in 1944 the pumpage had increased to about 100 mgd. In the El Paso area, the total consumption of water from wells was about 2 mgd. in 1910, 9 mgd. in 1920, 15 mgd. in 1930 and 26 mgd. in 1943. In central Arizona, the aggregate pumpage, mostly for irrigation, amounted to approximately 535 mgd. in 1940; in 1942 it was 695; and in 1943, 745 mgd. Similar increases in pumpage from wells have occurred in various other agricultural areas, such as the High Plains area of Texas.

Protection of Water Resources

There is every evidence that the development of additional and increased water supplies from surface and subsurface sources is going to continue. In fact, new industrial processes, such as the hydrogenation of coal, which will require huge amounts of water, are even now being perfected. It seems obvious that the rapidly increasing demands must eventually equal the readily available supplies of water. There are many local areas where this has already happened, and some states have taken steps to conserve their water supplies. It appears inevitable that the remaining states eventually will be forced into adequate programs of water conservation and utilization. A readily apparent step, of course, is protection against pollution. Many streams, especially in the East and Midwest, are so badly polluted as to be unusable, and several states have begun programs of pollution abatement. The pollution of ground water reservoirs is even more serious because ground water moves

so slowly that contamination, once introduced into a reservoir, may persist almost indefinitely.

In the early days of oil development, the improper casing of wells and the haphazard disposal of brines from oil wells ruined, or partially ruined, many valuable ground water reservoirs. In most states the casing of oil wells and the disposal of oil-field brines are now controlled by state boards. The disposal of chemical wastes on the land surface, however, is only partially controlled. Thus, in Ohio, a manufacturer has ruined his own ground water supply by pumping brine into a creek near his factory. In California, the Montebello incident (3) serves as an example of the harm that may be done by improper waste disposal:

In June 1945 a small plant manufacturing a weed killer, composed mainly of trichlorophenol, started operation in Alhambra. The waste, consisting of water used in cleaning out drums and washing down floors, plus some chemicals lost in the process, was discharged into the sewer system and passed through the Tri-City Sewage Treatment Plant, where it was diluted with 12 mgd. of domestic sewage. Chlorinated effluent from the treatment plant is discharged into the rising water of the Rio Hondo about one mile above the Whittier Narrows.

Within 17 days after the manufacture of the weed killer started, presence of phenols in the water caused eleven shallow wells in the Montebello Basin below Whittier Narrows to be shut down. These wells served some 25,000 people. It is reported that irrigation with this contaminated water killed lawns and shrubs. Operation of the manufacturing plant was stopped within 30 days after it started, thus preventing irreparable damage to water resources of the coastal plain. By December 1945 the pollution had traveled as far south as Downey, although somewhat diminished in intensity by reason of dilution. Several of the first eleven wells to show pollution are still contaminated.

A second step in protecting the nation's water supplies is to limit the withdrawal of ground water to the safe yield of the aquifer by mutual agreement or by statute, a subject which has seen considerable discussion. No comment is required except to note in passing that Arizona recently enacted a ground water control law, thus becoming the eighth state to control the use of ground water by statute.

Artificial Recharge

The prevention of pollution and the control of ground water withdrawals are steps in the protection of existing water supplies. In several areas, the water supply must be increased in order to maintain present developments. Increasing the available water supplies involves the salvage of water that would otherwise escape or the importation of water from surrounding areas. This usually necessitates the expenditure of large sums of money and requires a careful comparison of costs and benefits.

Early in this century, J. G. Richert (4) of Sweden extensively investigated artificial recharge—that is, the practice of increasing by artificial means the amount of water that enters a ground water reservoir. Artificial recharge is employed in many places in Europe and the United States but probably most extensively in California. One of the earliest artificial recharge projects in the United States was started by the Denver Water Co. in Colorado in 1889 (5).

Geology in Relation to Recharge

Ground water occurs in the saturated zones of permeable rocks—called aqui-

fers—such as sand and gravel, fractured or cavernous limestone, sandstone, lavas and the like. The extent, thickness, attitude and structure of these rocks vary widely, depending on the mode of their formation and on the geologic events that have occurred since they were formed. These permeable rocks range from broad sheets underlying areas of hundreds of square miles to small stringers or basins occupying the channels of prehistoric streams. The sands and gravels, especially, are likely to be overlaid, at least in part, by beds of shale or clay which are essentially impermeable. Thus, the water in the aquifer must enter it where it is exposed at the land surface.

Under natural conditions, water from precipitation or from streams or lakes enters a ground water reservoir in the outcrop area and moves by gravity to a point of discharge. Any procedure which increases the recharge—that is, the amount of water entering the aquifer—is called artificial recharge. Attempts at artificial recharge should be preceded by a thorough study of the geology of the aquifer, including the drilling of as many test wells as may be necessary. For example, a new source of well supply was developed recently at Canton, Ohio. The producing aquifers consisted of a shallow sand and gravel and a deeper sand and gravel, separated by a clay bed, filling an ancient river channel west of the town. Inasmuch as the storage capacity of the aquifers was relatively small, and the recharge area of the lower aquifer was distant, a source of recharge near by was necessary to secure an adequate perennial water supply. After extensive tests, a horizontal type of well tapping both aquifers was installed. During nonpumping periods, water in the upper gravel, which is recharged from the stream, enters the well and passes downward into the lower gravel. During periods of pumping, both aquifers yield water to the well at a rate of several million gallons a day (6).

Hydraulics of Recharge

In discussing the general principles of artificial ground water recharge, O. E. Meinzer (7) has pointed out that ground water reservoirs differ from surface lakes and reservoirs in the great frictional resistance which they offer to the movement of the water they contain. Consequently, ground water moves very slowly even under hydraulic gradients that are relatively high. Thus, some parts of a ground water reservoir may be filled considerably above the levels of its natural spillways. It is the slow movement of this water toward the natural spillways that provides the base flow of streams during dry weather.

On the other hand, if a stream crossing the outcrop of an aquifer lies above the level of the ground water, the movement is reversed and water seeps away from the stream to enter the ground water reservoir. Thus, if a well located near a stream that is fed by ground water is pumped until its cone of depression reaches the stream, the discharge of the stream is reduced; and if the cone is enlarged sufficiently to reverse the hydraulic gradient, the stream loses water into the aquifer. Additional ground water recharge can therefore be induced by pumping from wells near effluent streams. The ground water developments that have induced recharge from the Ohio River at Parkersburg, W.Va. (8), Louisville, Ky. (9), and Charlestown, Ind. (10), are outstanding examples of this

type of artificial recharge. Investigations on Nimishillen Creek have demonstrated that a large part of the pumpage in the northeast well field at Canton, Ohio, is derived from infiltration from that creek (11).

In view of the close relation between ground water and surface water, it is advisable to inquire whether a proposed large development of ground water will divert surface water that is already being used, and, conversely, in any new surface water developments, consideration should be given to the possible interference with existing ground water supplies. For example, the development of the well field at Big Spring, Tex., dried up the big spring from which the town took its name. On the other hand, the East Bay Dist. in California, before diverting water from the Mokelumne R., made an intensive investigation of the possible effects on the large irrigation supplies that were obtained farther downstream from wells (12, 13).

Artificial Recharge Methods

Meinzer (7) classifies methods of artificially increasing recharge into: (1) indirect methods, in which increased recharge is accomplished by locating wells as close as practicable to areas of rejected recharge or natural discharge; and (2) direct methods, in which water from a surface source is conveyed to points from which it percolates into a body of ground water. The direct method may be subdivided into recharge by surface application (14) and recharge through wells (15).

Perhaps the most widely used methods of artificial recharge are the several varieties of surface application, which are effective where the ground water level is below the stream level and where the formations at the surface are permeable. These methods have been adapted to different conditions. Where the water is quite clear, as at the Runyon Water Works and the Duhernal Reservoir in New Jersey, the surface water is stored in small lakes from which it seeps into the ground (16). If the water is silt-laden, it is conducted into recharge basins, usually after the heaviest silt has been allowed to pass downstream, and the basins are periodically rejuvenated, as in the Des Moines Water Works in Iowa (17), or as on the Rio Hondo in Los Angeles County, where the basins are periodically allowed to dry out and are deeply scarified. Another widely practiced method is to lead the water through ditches, from which it seeps into the aquifer, as in Hamburg, Germany (18); Dayton, Ohio (19); and several places in California (14). Provision must be made for periodically cleaning the ditches.

In the flooding method, practiced extensively in California, flood waters are impounded and then released at a rate determined by the infiltration capacity of the stream channel below the dam. It was believed that occasional flood flows were necessary to scour the silt from the channel in order to maintain normal infiltration. However, observations on Queen Creek, Ariz. (20), in 1940–41, when a flow of relatively clear water came down from the mountains for several months, showed that the infiltration rate gradually increased, presumably because the clear water picked up and carried away the fine-grained materials.

Recharge into pits has been successfully practiced at Valley City, N.D., where river water is led into gravel pits, and on Lytle Creek in California

(14). This method requires very clear water, however, or the pit becomes clogged with silt.

Recharge through wells involves distinctive difficulties and limitations because, except in cavernous limestone terranes where there is little danger of clogging if reasonable precautions are observed, the recharge wells usually become clogged and progressively less effective. On Long Island, N.Y., however, the water used in cooling is returned to the formation without being exposed to the air. There are now over 300 recharge wells on Long Island, many of which are capable of returning as much as 1,000 gpm. to the aquifers. Many of them have been in operation for more than five years without failing. The total water returned to the formation aggregates about 60 mgd. (21).

Water Temperature and Quality

Much of the demand for ground water is due to its low and uniform temperature, which in the summer is lower than that of surface water, and to its uniform quality. If the formation is recharged by surface spreading and the point of withdrawal is at a considerable distance from the point of recharge, it is assumed that the artificially recharged water will have about the same temperature characteristics as the naturally recharged water. But when water used for cooling is returned to a formation through wells that are near pumped wells, as on Long Island, the temperature of the ground water slowly rises (21) and it is less effective for cooling purposes. Induced recharge from streams, as in the Charlestown, Ind., and Parkersburg, W.Va., projects, does not have the uniform temperature characteristic of ground water. Jeffords (8) has shown that the temperature ranges from 46° to 66°F. at Parkersburg, and Kazmann (10) reports a range of 47° to 72°F. at Charlestown, Ind. However, the temperature of the ground water fluctuates through a narrower range than that of the water in the near-by stream, and therefore the ground water still has a substantial advantage over stream water for cooling purposes.

Certain tastes and odors in the Ohio River water, especially those derived from phenolic wastes, have proved difficult to remove from surface waters. These tastes and odors apparently have not reached the wells at Parkersburg, although they are only 150 ft. from the river and the plant has been in operation since 1929 with direct evidence of recharge from the river. In other areas, as in California, phenolic wastes are known to have traveled distances of at least 1,800 ft. through the aquifers.

Recharging with cold treated surface water during the winter months will tend to lower the temperature of the ground water. This was done on a small scale in Louisville, Ky., during the war, with definitely beneficial results (9), and it has been carried out effectively for several years at Hopewell, Va. (22). More recently a measured quantity of fresh cold city water was forced into a brackish well at Camp Peary, Va., to determine whether fresh water could be stored in the brackish water formation. Later, when the well was pumped, the water was fresh and cold until a quantity of water equal to about half the fresh water introduced had been withdrawn. Then further pumping produced water that was warmer and progressively more highly mineralized. It is believed that larger proportions of the amounts recharged could be recovered

in subsequent years. Although the experiment was conducted on a small scale, the method showed promise (23).

Conclusions

As a result of the enormous increase in the use of water, many areas in the United States are faced with actual or potential shortages. In many places these shortages can be solved at least temporarily by relatively simple measures, such as the abatement of stream pollution and the reduction of sedimentation. Where ground water is used, waste resulting from continuously flowing wells or defective casings can be reduced; heavy concentrations of pumped wells in restricted areas can be eliminated, thus preventing excessive drawdown and salt water intrusion from the sea or from overlying formations. In other places, where the safe yield of the ground water aquifers has been exceeded and the available reservoir sites have been utilized, it may be necessary to transfer excess industries and populations to regions where undeveloped water supplies are available. There are, of course, numerous areas throughout the United States which have water supplies that will be adequate for many years to come, provided proper measures based on full information are taken to protect and conserve the existing supplies. Where the geographic and economic advantages warrant it, however, water may be imported from considerable distances, as has been done in various parts of California, at New York City and elsewhere.

In those areas where the water supply is inadequate and the expenditure of substantial funds for providing additional supplies is warranted, the salvaging of flood water and its storage in the ground water reservoirs by means of artificial recharge should be fully investigated. The possibility of inducing recharge from surface streams to ground water formations should be examined if uniformity of temperature and quality are substantial considerations. Although artificial recharge is not everywhere feasible and is often not necessary or practicable under present conditions, it has been eminently successful in a considerable number of places where it has been attempted. It is believed that, as the use of water approaches the limits of the available supply in other parts of the country, artificial recharge will assume increasing importance in the national economy.

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Ground Water Recharge on Long Island

By Arthur H. Johnson

A paper presented on May 4, 1948, at the Annual Conference, Atlantic City, N.J., by Arthur H. Johnson, Assoc. Engr., State Water Power and Control Commission, Jamaica, N.Y.

LONG Island, a part of the state of New York, is situated in the Atlantic Ocean northeast of New York City. This island is separated from the mainland of New York and Connecticut by the East R. and Long Island Sound, the latter a body of salt water varying from 1 to 15 miles in width. The shape of the island resembles that of a large fish with its head pointed toward, and forming a part of, New York City and its tail, at the extreme end of the island, forming the north and south flukes (*see* Fig. 1). Long Island is about 120 miles long and 23 miles in breadth at its widest point. Its land area, divided into four counties, totals approximately 1,373 square miles.

The most recent population estimates indicate that nearly 5,000,000 persons dwell on this island, 4,200,000 residing in the westerly third in the counties of Kings (Brooklyn) and Queens, which are part of New York City. Two other counties, Nassau and Suffolk, make up the easterly two-thirds of the island. Nassau County, with an estimated population of 500,000 persons, includes many large estates, some of which are rapidly being developed into residential communities, while the central part of the county appears to be developing into an industrial area. In general, it may be said that a large proportion of the residents are commuters to various sections of New York City.

Suffolk County, the largest in area, is the smallest in population of the four Long Island counties, being made up of many farms and estates. Its present industrial development is relatively small.

The topography of Long Island is fairly uneven. There are two glacial moraines, the older extending from the eastern end of the south fluke diagonally across the island and along the north shore. The more recent moraine forms the north fluke and extends in a southeasterly direction to cross the older moraine at Lake Success, located about 20 miles east of New York City. The northern shore of Long Island consists of rolling hills indented by numerous bays and harbors. This hilly section extends generally in an east-west direction along the backbone of the island, sloping gently toward the southern shore, which is made up of low plains enclosing broad shallow bays and is bounded by a barrier beach. Water used by the residents of Long Island is obtained from wells and small surface streams, except for some Catskill water supplied by the city of New York to certain areas of Kings and Queens counties since 1924. On June 30, 1947, public water supply

wells supplying the Flatbush area in Kings County were shut down.

Immediately after World War I, as a result of increasing industrial development in Kings and Queens, many wells of large capacity were put down. These were located throughout the concentrated industrialized area of Kings County and at first were relatively shallow, many being dug wells of the open-brick type operated by steam suction pumps. Uncontrolled drilling, increasing year after year in this industrialized area, resulted in the lowering of the water table and the salting of many large private and public water supply wells in the northern and western areas of Brooklyn. In 1932 the New York Water Service Corp. (supplying Flatbush), the city of New York and the Jamaica Water Supply Co. made a joint study of existing ground water levels in Kings County. This survey revealed how widespread was the depression in static levels under western Long Island and how far inward salt intrusion had advanced. Pumping equipment at the time consisted mostly of the vertical-plunger pump, although some centrifugal pumps were in use. The lowering of the water table, however, led to the introduction of the deep well turbine pump, which is now used almost exclusively throughout Long Island.

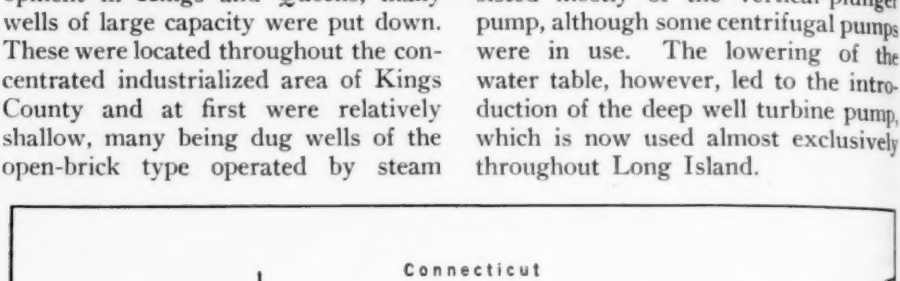

FIG. 1. Long Island, N.Y.

Prior to 1933 the use of wells as a means of returning water into the ground had been but little employed.

Commission Control

On April 28, 1933, Section 521-a of the Conservation Law was passed by the New York State Legislature, placing the ground water resources of Long Island under the jurisdiction of the Water Power and Control Commission. Since that time the commission has prohibited the drilling of new

industrial wells with capacities in excess of 69.4 gpm. (100,000 gpd.), unless the water pumped is returned in an uncontaminated condition into the ground through diffusion wells or other approved structures. This process, a matter of conservation, is usually referred to as diffusion.

Dating from the enactment of Section 521-a of the Conservation Law there have been 347 well type diffusers or diffusion wells put down on Long Island, approximately 300 of which are in use at present. The design and construction of the first diffusers or diffusion wells included a wide variety of types:

1. Open pits of 30- and 36-in. steel casings were put down to the water table, the water diffusing through open slots, ¼-in. wide by 3 in. long, burned through the lower casing.

2. Plain steel casings were driven into the water-bearing formations with a slotted section placed at the bottom serving as a screen.

3. Steel casings 24 and 36 in. in diameter were sunk into water-bearing formations, a slotted casing being attached to the smaller casing and lowered to the bottom. Selected gravel was then placed between the outer and inner casings, and the outer casing withdrawn up to the water table or in full, thereby leaving the slotted section exposed to the gravel wall and the permeable formation.

At present standard well screens of Everdur * or other approved materials are usually specified and due consideration is given to the quality of the water to be diffused. It is now the general policy of the commission to have the screen set in the same water-bearing formation from which the supply is being drawn. Actually, the state is interested only in results, but it found that it must take steps to assure at least reasonably good design and construction, both to conserve ground water and to protect and help the drillers and their customers. To this end, a conference was held, attended by drillers, engineers, government representatives and others, at which substantial agreement was reached on what could and should be done.

TABLE 1

Applications for Air Conditioning

Year	Number of Applications			
	Filed	Completed Works Approved	Rejected, Lapsed or Canceled	Pending
1933	0	0	0	
1934	22	0	5	
1935	39	0	14	
1936	111	18	64	
1937	43	34	23	
1938	27	50	8	
1939	36	29	16	1
1940	45	13	27	1
1941	29	21	9	
1942	10	15	6	
1943	19	7	6	
1944	3	3	18	2
1945	16	5	0	3
1946	35	7	0	17
1947	22	19	0	16
Total	457	221	196	40

Subsequently the drillers and engineers drew up a set of specifications which were thereafter taken into consideration when applications for approval of diffusion well projects were submitted to the state. The state did not formally adopt these specifications, but it largely followed them.

As time went on, it appeared wise for the state to set up minimum re-

* A product of the American Brass Co., Waterbury, Conn.

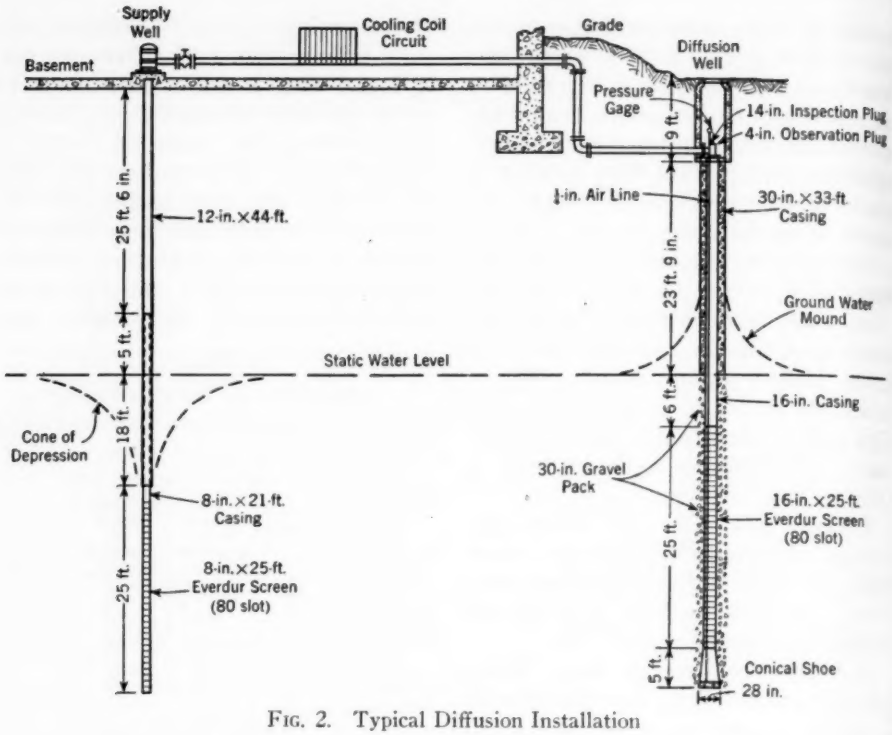

FIG. 2. Typical Diffusion Installation

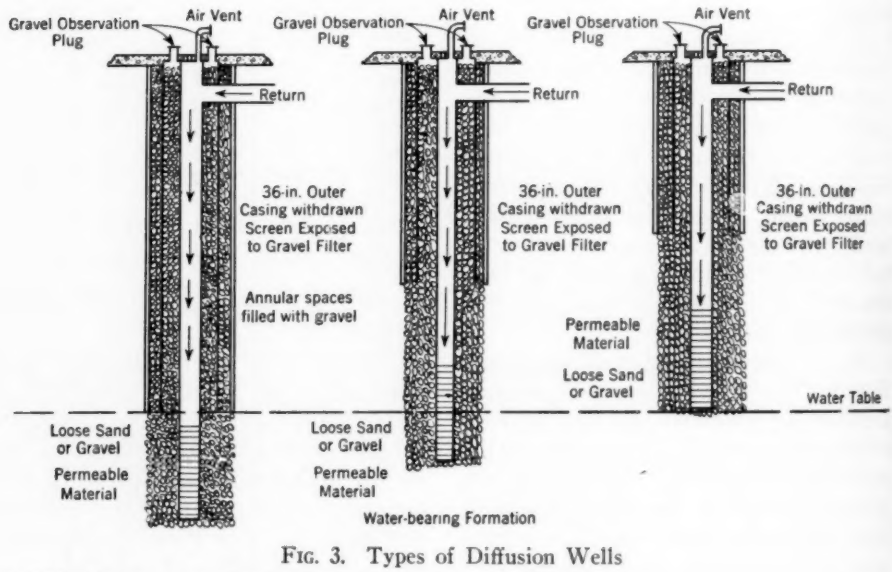

FIG. 3. Types of Diffusion Wells

A—Diffusion screen completely exposed to water-bearing formation.
B—Diffusion screen exposed partly to water-bearing formation and partly to permeable (nonwater-bearing) formation.
C—Diffusion screen completely exposed to permeable (nonwater-bearing) formation, with bottom of screen at water table.

quirements, and another conference was called to discuss the matter. A reasonable concordance of thought could not be obtained and the subject was left for further study and consideration. Much has since been learned about diffusers, and tentative rules and specifications are being formulated. A typical diffusion well is shown in Fig. 2.

The first well officially recorded as being exclusively for diffusion was put down in 1933 at the Canarsie Theatre in Kings County. This well was 50 ft. deep with a 6-in. diameter casing and 8 ft. of slotted pipe for a screen. Water was pumped from the supply well at a rate of 200 gpm. for use in air conditioning the theatre, and was then discharged into the diffuser. Although requiring periodic cleaning, this diffusion well is still in service during the air-conditioning season of approximately 100 days a year. About this same time three other wells were sunk at the Oceana Theatre in Brighton Beach, Kings County. These wells were set into the water-bearing formation with 6-in. slotted steel casings, to a depth of 60 ft. Two of the wells have since been abandoned. At least six other wells put down in 1933 or before as supply wells have been converted to diffusers. Two of these at the Liebmann Breweries are still in use.

The first application to be filed with the commission for a diffusion well was on May 4, 1934. A hearing on this application was held on June 8, 1934, and approval was given by the commission on June 18. Under the authority of that decision, a diffusion well was sunk at the Richmond Hill Theatre in Queens County, with a 30-in. outer and 10-in. inner casing, to a depth of 95 ft. below ground surface. The lower 10 ft. of the inner casing consisted of burned slots about ½ in. wide and 3 in. long. A 2-in. gravel wall was placed around the slotted part of the casing. In September 1947 this well diffused water from air-conditioning operations at a rate of 200 gpm.

On July 1, 1935, Section 521-b of the Conservation Law was enacted re-

TABLE 2

Diffusion Well Screen Setting

County	Below Water Table		Half Above and Half Below Water Table		Above Water Table	
	In Use	Out of Service	In Use	Out of Service	In Use	Out of Service
Kings	79	15	18	0	34	4
Queens	62	11	16	2	13	1
Nassau	60	4	9	0	4	0
Suffolk	15	0	0	0	0	0
Total	216	30	43	2	51	5
Per Cent	88	12	96	4	91	9

TABLE 3

Diffusion Well Capacities

	No. of Wells	Capacity *gpm.*
	133	100–250
	53	250–350
	37	350–450
	20	450–550
	22	Over 550
Total	265	

TABLE 4

Quantity of Well Water Diffused, 1936–46

County	Year			
	1936	1944	1945	1946
	mgd.			
Kings	3.73	7.94	7.50	7.75
Queens	1.00	5.20	4.37	4.30
Nassau	0.66	5.90	6.00	6.30
Suffolk	0.13	1.26	1.29	1.32
Total	5.52	20.30	19.16	19.67

quiring all well drillers operating on Long Island to be licensed. A charge of $2.00 was made for an annual license fee. On January 1, 1948, about 150 well drillers were licensed to operate on Long Island.

About the time the control of ground water on Long Island was placed under the regulation of the Water Power and Control Commission, the popularity of air conditioning began to increase—a trend which still continues. Up to January 1, 1948, a total of 457 applications had been filed with the commission to sink wells for use in air-conditioning or cooling. Of this number, 221 completed works have been approved; 196 have been rejected, have lapsed or have been canceled; and 40 are pending or uncompleted (*see* Table 1).

Wells have been constructed to diffuse above, below, and partly above and partly below the water table (*see* Fig. 3). It was first thought that the most successful wells were those with screens set below the water table. An investigation of 319 diffusers, however, showed that the best results were obtained by diffusers with screens set

TABLE 5

Quantity of Well Water Diffused, 1947

County	Air Conditioning	Other Industrial Use	Total	Annual Mean‡	Seasonal Mean§
	mil.gal.			*mgd.*	
Kings	1,751.2	980.5	2,731.7	7.7	21.2
Queens	1,034.3	838.0	1,872.3	5.2	13.4
Nassau*	492.0	2,644.9	3,136.9	8.7	12.5
Suffolk†	88.8	496.0	584.8	1.6	2.3
Total	3,366.3	4,959.4	8,325.7	23.2	49.4

* Nassau industrial total includes 443 mil.gal. diffused through open recharge basins.
† Suffolk industrial total includes 349 mil.gal. diffused through open recharge basins.
‡ Based on 365-day operation for all wells.
§ Based on 100-day operation for air-conditioning wells and 365-day operation for other industrial wells.

TABLE 6

Total Industrial Pumpage, 1936–47

County	1936	1944	1945	1946	1947
	Pumpage—*mil.gal.*				
Kings	32,000	12,180	9,230	9,194	8,867
Queens	8,300	6,600	4,860	5,540	4,712
Nassau	299	2,591	2,652	2,760	3,785
Suffolk	120	1,006	1,067	1,103	1,244
Total	40,719	22,377	17,709	18,597	18,608
Kings					
Pumpage not Diffused	13,000*	3,600	5,050	5,300	5,300
Pumpage Diffused	13,000	7,800	3,800	3,540	2,732
Unreported*	6,000	780	380	354	835
Total	32,000	12,180	9,230	9,194	8,867
Queens					
Pumpage not Diffused	1,500	1,340	2,320	3,270	2,440
Pumpage Diffused	6,200	4,760	2,240	2,070	1,872
Unreported*	600	500	200	200	400
Total	8,300	6,600	4,760	5,540	4,712
Nassau					
Pumpage not Diffused	48	420	430	435	618
Pumpage Diffused	241	2,150	2,200	2,300	3,137
Unreported*	10	21	22	25	30
Total	299	2,591	2,652	2,760	3,785
Suffolk					
Pumpage not Diffused	50	500*	550*	575	600
Pumpage Diffused	47	460	470	480	585
Unreported*	23	46	47	48	59
Total	120	1,006	1,067	1,103	1,244

* Estimate.

partly above and partly below the water table. This result may be misleading because of the small number of wells constructed in this way in comparison to the number with screens set below the water table. The success of some dry diffusers may be due to their screens being set in the upper glacial formations—made up of boulders, coarse sand and gravel—where

little or no added gravel pack is required. It is also probable that a large part of the region in which many successful dry diffusers have been put down was originally a water-bearing formation prior to the development of heavy pumping in that area. The efficiency of wet diffusers may result in part from periodic servicing and cleaning.

The data shown in Table 2 were obtained in 1946 and 1947 from investigations of the maintenance and operation of a majority of the diffusion wells on Long Island.

Diffusion Well Statistics

On January 1, 1938, there were 95 air-conditioning and 11 industrial plants diffusing an estimated 29 mgd. of water during the air-conditioning season of about 100 days. Comparable figures for January 1, 1947, indicate that 197 air-conditioning and 25 industrial plants diffused about 49.4 mgd. during the cooling season.

Diffusion well capacities varied from 100 to over 550 gpm., as shown in Table 3. Of the total in Table 3, 221 are in service during the air-conditioning season and 44 operate all year round.

Table 4 indicates to what extent well water used on Long Island in industrial operations is returned into the ground. In Table 5 the figures for 1947 are broken down into air conditioning and other industrial use.

Prior to the enactment of Section 521-a of the Conservation Law, water pumped from the many industrial wells on Long Island was wasted into the sewers or into the sea after use. The amount of well water used for air conditioning and other industrial purposes which is returned to the ground increased from 29 mgd. in season in 1937 to 49.4 mgd. in 1947. During the same period the total industrial pumpage from wells not diffusing decreased from 14,598 mil.gal. in 1936 to 8,958 mil.gal. in 1947, or approximately one-third. This decrease may have taken place for several reasons: many old wells sunk prior to 1933 have been abandoned and replaced by diffusion installations; numerous war plants have closed or reconverted and now operate on a single shift; some industrial plants have been relocated from Kings and Queens to the less populated areas in Nassau and Suffolk.

Table 6 shows the total industrial pumpage (including air conditioning and other industrial use) for 1936–47. These figures are then broken down for each county into "pumpage not diffused," "pumpage diffused" and "unreported." No information is available on whether or not the pumpage listed as unreported was diffused.

No complete recovery in water levels in Kings and Queens is possible without 100 per cent diffusion of all well water now being wasted, including wells which antedate the present law. Contaminated water would require treatment before being diffused.

There is one phase of the problem which is progressively getting worse and may ultimately change the present concept of diffusion. This is the rise in temperature of the ground water itself when used for cooling. Apparently the winter season is not of sufficient duration, nor the natural recharge great enough, for the water to cool itself, a condition which is further aggravated by the year-round operation of many wells in the areas of concentrated pumping.

The Water Supply of Puerto Rico

By Sergio Cuevas

A paper presented on May 5, 1948, at the Annual Conference, Atlantic City, N.J., by Sergio Cuevas, Administrator and Chief Engr., Aqueduct and Sewer Service, San Juan, P.R.

THE island of Puerto Rico, a possession of the United States since 1898, when it was ceded by Spain under the Treaty of Paris, is the smallest of the Greater Antilles. It has a total area of 3,435 square miles, including the near-by small islands of Vieques, Culebra and Mona. The population is estimated at 2,100,000 inhabitants, thus placing Puerto Rico among the most densely populated regions of the world. Essentially an agricultural island, the growing and processing of sugar cane is the principal industry, producing approximately 1,000,000 tons a year. The distillation of rum is a related enterprise, depending on a by-product of sugar. The needlework industry, using imported materials, ranks second. Tobacco, coffee and fruits are exported to some extent.

In an effort to free the island from the uncertainties and the latent danger of depending on a single crop, sugar, the insular government is sponsoring a vast program of industrialization. Plants have been built for producing Portland cement, glass containers, paper, ceramics, leather goods, rugs, textiles and composition board.

The government during recent years has adopted a program of general improvements to better the health, economic and social conditions of the people of the island. The construction of new water supply and sanitary sewer systems, and improvements to the existing systems, is necessary to carry out this program.

Prior to 1945 supplying water and furnishing sewer service to the urban and rural population was a function of each of the 77 municipal governments of Puerto Rico. Local facilities were often inadequate to cope with the demands of a rapidly increasing population, and few towns had 24-hour water service.

The rural population, amounting to 60 per cent of the total, had no public water supply, being dependent on unsanitary shallow wells, polluted creeks or rain water collected in barrels.

Aqueduct and Sewer Service

The unsatisfactory situation resulting from the independent operation of the municipal systems prompted the insular government to request the Legislature of Puerto Rico to approve a law creating the Puerto Rico Aqueduct and Sewer Service. This act, passed in 1945, states:

> The Service is created for the purpose of providing and helping to provide to the inhabitants of Puerto Rico, at the lowest possible cost, an adequate service of sanitary sewage disposal and an ample regular supply of pure water for domestic, industrial and commercial purposes; and to provide them with any other service or facilities incidental thereto or appropriate

in connection therein. The Service shall have and may exercise all rights and powers necessary or convenient for carrying out said purposes, including, but without limitations, the following: perpetual existence as a corporation and all powers, obligations and attributes incidental thereto; [to] adopt a seal; [to] sue and be sued, except for damages arising from impurity, irregularity or insufficiency of the water supplied; to make contracts; to acquire all kinds of property; [to] appoint agents and employees; to borrow money and issue bonds; to accept grants or gifts.

The Service shall have no power at any time or in any manner to pledge the credit or taxing power of the people of Puerto Rico or any of its political subdivisions.

In order for the Aqueduct and Sewer Service to have control of all water supply and sanitary sewer systems run by the municipalities, the act provided for the transfer to the service of all useful property and water franchises operated or controlled by the people of Puerto Rico, or its political subdivisions, for the disposal of sewage or for supplying water for domestic, industrial or commercial use.

As a public corporation, the service is regulated by a governing board composed of the Governor of Puerto Rico, the Treasurer and the Commissioners of Health, Interior and Labor. The service exercises its power through an Administrator and Chief Engineer, subject to such rules and regulations as may be enacted by the board. The board appoints the Administrator and Chief Engineer, the Auditor and other officers.

Service Activities

The first activities of the service began in December 1944 with the transfer of the metropolitan water supply system, serving San Juan (the capital of Puerto Rico) and four adjoining towns with a total population of over 300,000 inhabitants. During the year 1945–46 the responsibility of operating and administering all the water supply and sanitary sewer systems of the island was placed on the service, which was organized as a public utility. A new uniform rate for water and sewer service was established and standards of operation and work were set up.

The first step was to prepare a record of all water consumers and create in them the habit of paying for their water and sewer service. This aspect of the work was successfully accomplished by an extensive educational program, using printed pamphlets, newspapers, the radio, the schools and personal visits by water service employees to thousands of homes. As a result, not only is the water being paid for, but waste has been reduced considerably. Uniform rates were established: a minimum flat rate of 60¢ a month for domestic service and a metered rate starting with a minimum charge of 60¢ a month for the first 15 cu.m. or fraction thereof. There were approximately 70,400 customers on the books during the first year of operation, and the total consumption amounted to approximately 38 mgd. In the first year seventeen new sanitary sewer systems were constructed and major improvements were made to the existing water works at a cost of approximately $1,700,000. The service was greatly handicapped in its first program of construction by difficulties in obtaining material such as cast-iron pipe, as well as by the lack of shipping facilities for transporting the few materials that were available. All construction materials, with the exception of cement, sand and stone, are imported from the continental United States.

In the second year of operation the number of customers increased to 95,300 and the water served amounted to almost 50 mgd. At present there are 98,500 customers using 61 mgd. The services are 58 per cent metered, with additional meters being installed at the rate of 1,800 a month.

The water is obtained chiefly from surface supplies, which are fully treated in ten modern filtration plants with a combined capacity of 40 mgd. Partial treatment plants deliver 14.6 mgd. and deep wells produce 7 mgd., making a total of 61.6 mgd. for the entire island of Puerto Rico.

Of the 77 towns 56 are supplied with surface water, while 21 get their water from deep wells by means of electric pumping units. The sudden, heavy showers of short duration cause high turbidity in the streams and rivers of the island and present complicated problems of treatment.

Construction Projects

A very important function of the service is to provide an adequate supply of pure water to the people of the rural areas, who make up 60 per cent of the total population. Considerable difficulties are encountered because of the scarcity of sources, the hilly topography and the high cost of construction. There are 216 rural aqueducts (small water supply systems) on the island, furnishing much of the rural population. Many of these people are unable to pay for water service, however, and the insular government provides the money for the installations. At present $1,350,000 from public funds is being spent by the service in the construction of 30 rural aqueducts for the benefit of the people.

Immediate plans call for insuring an adequate supply for the San Juan Metropolitan Dist., which includes the city of San Juan proper and eleven adjoining towns, with an estimated population to be served of nearly 450,000 in 1950. The existing available supply is 31 mgd., while it is estimated that there will be a demand of 38 mgd. by 1950. The project, now under construction, to provide an additional supply for the Metropolitan Dist. will develop the watershed of the Rio Grande de Loiza. This project consists of a concrete gravity dam, 108 ft. high with eight Taintor Gates, each 30 ft. high and 39 ft. wide, and a net spillway length of 312 ft.; the impounding reservoir will store 4,550 mil.gal. on a watershed of 208 square miles.

A powerhouse and pumping station will be constructed at the dam. A transmission main, 3.3 miles long, of 48-in. reinforced concrete pipe will carry the water to a 30-mgd. filtration plant also to be constructed; from there the water will be delivered to the present distribution facilities. The estimated cost of the project is $6,600,000. The initial development will provide 30 mgd., and ultimately a total of 60 mgd. will be attained.

A comprehensive system of sanitary sewers for the populated areas of San Juan and its rapidly growing suburban zone is contemplated. In general, the project comprises a system of trunk lines and lateral sewers and a pumping station and modern treatment plant of sufficient capacity to treat the sewage effluent for many years.

Many special jobs to improve the service have been in progress during the past year, such as the cleaning of 330,000 ft. of 4–20-in. water mains. Pitometer surveys have been made in the larger towns to discover waste and provide information for future improvements.

All water served to the public is checked by the Dept. of Health and meets the requirements of the U.S. Public Health Service at all times.

The complete program of improvements which is being developed requires an investment of $25,000,000 for water works facilities and $13,500,000 for sewage works, to be financed by means of revenue bonds authorized by the enabling act. It is expected that the program will be completed within five years.

There is a tremendous amount of work still to be done, but the accomplishments of the Puerto Rico Aqueduct and Sewer Service in the past two years of operation are worthy of note. The service feels confident that its goal will be reached and that the program to supply abundant and pure water to all the people will be fulfilled.

Solving Havana's Water Problems

By Manuel J. Puente and Jose Garcia-Montes

A paper presented on May 5, 1948, at the Annual Conference, Atlantic City, N.J., by Manuel J. Puente, Cons. Engr., and Jose Garcia-Montes, Civ. Engr., Havana, Cuba.

IN 1544 the inhabitants of the village of San Cristobal de la Habana, needing more potable water, requested of the King of Spain, Charles I, permission to build a canal from the Almendares River to the village, then nothing more than a small township.

The royal permission was granted, but for 44 years thereafter the inhabitants could not agree on how to build the canal, who was to build it and how it would be operated. It was not until 1588 that a property owner named Manrique de Roxas offered a plan for the canal and proposed to build and operate it for a service fee from those receiving the water. Roxas' plan was accepted after much debate.

What Roxas built was the Zanja Real (Royal Ditch), the first water works built by white men in the Western Hemisphere. After a few years of service Roxas' work was practically destroyed by a flood in the river. This happened while the celebrated architect Antonelli was being retained in Cuba to build the fortress known as Castillo de la Fuerza. Under the direction of Antonelli, the control works and the intake to a new canal were built in 1592. The control dam and valve house are still standing.

For 240 years Antonelli's canal, originally conceived by Roxas, was the only source of supply for the increasing population. Then, without any discussion or debate that the records mention, King Ferdinand VII ordered the construction of a filter house to treat the Almendares River water and the piping of the effluent to the city. In 1831 these early filters and the pipeline were designed by Spanish military engineers. The filters apparently were something of an experiment; sponges were used as the filter medium. The filter house is still standing, but the whole project was a total failure; the effluent was plain raw water and, because of some gross mistake in the computation of the capacity of the pipe, the amount of water delivered was actually about one-tenth of what it was supposed to be. The 14-in. cast-iron pipe laid at that time within the city limits is still in use, however. The water was not, of course, piped to the dwellings but delivered to a number of public fountains.

Albear's Aqueduct

Notwithstanding the failure of the Ferdinand VII aqueduct, nothing more was done until the 1870's when the great Cuban military engineer Don Francisco de Albear suggested a gravity supply from the Vento springs, located at a distance of approximately six miles from Havana. Albear succeeded in isolating in a masonry basin, close to the Almendares River, outcropping springs that yield an unvarying supply

of 45 mgd. of wholesome water. This flow was conveyed by gravity through a masonry aqueduct to storage tanks at an elevation of 90 ft. above sea level. Havana was a city of about 100,000 population at the time that the Albear water works were finished.

As the years went by and more water was needed, a new collecting basin, not far from that built by Albear, allowed an additional 15 mgd. of spring water to be sent through Albear's aqueduct to the city. This work, together with some earlier extensions to the distribution system, was designed by Enrique J. Montoulieu. Finally, in the late 1920's, a new source was developed some 4 km. from Albear's basin, after considerable investigation and tests by many Cuban and foreign engineers. This new source, known as Aguada del Cura, increased the supply of subterranean water by an amount varying according to season from 16 to as much as 30 mgd.

The old aqueduct built by Albear, designed for gravity flow, is being taxed beyond its capacity by a flow of 70–85 mgd. or more, under a head of over 3 ft. It is doing the job but several breaks have occurred, with losses of 4–5 mgd. through small cracks.

The increasing elevation of delivery at the entrance to the Albear aqueduct has caused a substantial reduction in the yields of the springs at Vento. As a matter of fact, the combined yield is at present not over 75–77 mgd., including the Aguada del Cura supply.

Of Havana's total of 84–90 mgd., 12–18 mgd. is raw river water which is admitted at Vento in the Montoulieu collecting basin. A control dam across the river, said to have been built for the purpose of providing a head against the escape of some springs from the collecting basin, allows the water from the river to enter the basin. The normal level in the river is lower than the water inside the basin, an obvious consequence of the springs outcropping in the basin.

Although the total volume of water that comes to the city would appear to be enough for its population of about 700,000, the growth of the distribution system has not paralleled the increase in supply. Since Albear's pipes were laid, the city has not only grown in size but has also been extended to higher elevations. Pumping has been required since the early 1900's; at present approximately 50 per cent of the total amount of water used has to be pumped to elevations from 80 to more than 200 ft. above sea level.

The gravity supply from Albear's storage tanks to the low-lying sections, with a population of over 250,000, is still conveyed through his original 42-in. main. Because of the increasing height of buildings in that area, together with the considerable loss of head caused by the small-diameter pipes, many years ago the practice was begun of "injecting" water under pressure from the higher districts into the gravity supply. This practice was followed without any specific plan in the various water circuits, except that in some sections the pressure was provided by booster stations. Old valving and unscrupulous operation of the system have caused the intermingling of the gravity and pressure supply to such an extent that no one knows with certainty where one starts and the other ends. To a lesser degree, this situation already existed in 1928, at the time the late Allen Hazen was called into consultation by Pres. Menocal. Hazen reported that the condition of the distribution system of Havana must be remedied immediately. The action

taken, however, was limited to a few extensions of small pipes by the water works authorities and an increasing installation of cisterns, elevated tanks and house pumps by property owners.

The underlying problem of the insufficient capacity of the distribution pipes is not understood by the public at large, which has continually been calling for more water. As in 1544, the inhabitants of Havana all agreed that something had to be done, but they were not able to decide what kind of system to construct or how it should be operated.

While this state of affairs continued, many engineering reports were sought and obtained; a complete list of them would be a large one. The numerous reports by Cuban and foreign engineers contributed in part to the chaotic situation because of the conflicting opinions expressed. The municipal authorities and the public could not well understand the engineers' disagreements on many aspects of the subject.

In 1934 the authors, after close contact with the problem in their respective capacities of manager and chief designer of the Havana water works, decided to draw up, at their own expense, a complete project for the rehabilitation of the system. Plans were submitted to the city in 1940 but arguments, discussions, committees and politics stood in the way for the next four years. In 1944 all of the civic organizations and the municipal authorities had come to an agreement adopting the authors' proposals in full. The cost ran to eight figures and was to be financed with foreign capital. Politics again interfered, however, as the opponents of the plan insisted that the financing must be done with Cuban capital.

In 1946 a new mayor was elected on a platform dedicated to solving the city's water supply difficulties. Once more experts from different countries were called upon to present their ideas and opinions. Finally the mayor determined to proceed with the authors' project, but, in view of the opposition that his own party had carried on, he could not accept foreign financing, and his efforts to finance the work from domestic sources met with failure.

The succeeding municipal administration, however, decided to start work immediately, and, even while discussing with the authors the completion of an over-all plan, began the construction of a new 66-in. conveyor to the city, built in place, of reinforced concrete. All engineers agreed on the necessity for this conduit.

Description of Project

The unusual thing about this project is the fact, already mentioned, that the authors drafted it and paid the considerable expenses involved without the least assurance that it would be adopted by the city.

Briefly, the project divides the city, according to its topography, into four zones: a so-called gravity zone, from sea level to 50 ft. above; a first pumping zone, in which the area to be served is from 50 to 115 ft. above sea level; a second pumping zone, serving the houses located between 115 and 182 ft. above sea level; and a third pumping zone, which includes all elevations 182 ft. or more above sea level.

To ascertain the present distribution of the city's population and its density within each zone, and to estimate the population 25 years hence, a method was developed—based on the data obtained from the five censuses taken between 1899 and 1943—which gives the population in each of the 43 boroughs. Once the population by zones was es-

tablished, a quota was assigned varying from 60 to 200 gpd. per capita according to their characteristics. The sum of the population of each district times the allotted quota gave the total consumption to be provided. The total population worked out to be one million inhabitants.

Havana is now supplied by the Vento and Aguada del Cura sources and the Almendares River. In the future the city will be served by:

1. Aguada del Cura, where extensions will be made to increase the present yield from a mean of 18 mgd. to 30 mgd.

2. Vento, whose springs will be made to yield 65 mgd. by lowering the intake level at the entrance to Albear's aqueduct.

3. A new source to be developed in the eastern underground basin of the Almendares River, from which at least 30 mgd. can be drawn.

In this manner, all the surface water now taken from the Almendares River will be eliminated.

Several sources can be tapped in the eastern basin, such as the Chorrera de Managua, the Catalina wells and the rich springs at Cacahual which outcrop freely on the surface today with a minimum yield of 6 mgd.

As compared with today's single aqueduct (Albear's canal), the project calls for three separate aqueducts.

The Aguada del Cura supply will be pumped directly to Capdevila Hill, where an 18-mil.gal. tank will be built at a height of 200 ft. above sea level. The areas between 50 and 115 ft. above sea level will be supplied from this tank by gravity. Water from the Aguada del Cura source will be pumped through a 48-in. diameter pipe to join a new 60-in. main starting at Vento. Thus, the present costly practice of raising the Aguada supply to 200 ft. and then letting it drop to the Palatino tank elevation of 95 ft. will be eliminated.

The total production of the Vento springs will be carried by gravity through the Albear canal to the Palatino tanks, where two additional reservoirs of 7.5 mil.gal. each will be built, increasing the reserve capacity of the Palatino tanks to 30 mil.gal.

From the new source in the eastern Almendares basin 30 mil.gal. will be pumped; part of this volume will be conducted through a 24-in. main to a tank to be built on the Güinera Hill, at an elevation of 282 ft. above sea level; the rest will flow through a 42-in. main to join the Aguada del Cura supply at Vento and then through the 60-in. main to feed the Capdevila Hill tank. From the Güinera tank the higher elevations of the city—including Timon Hill and other high points in the Víbora section—will be served by gravity.

Planned Improvements

Extensive repairs will be made to the Vento basins and the Albear canal making possible the use of this gravity system for another 50 years.

The three aqueducts—the Albear canal and two new ones with sources at Aguada del Cura and the eastern basin of the Almendares—will be interlocked at two points: at Vento, through which the three conduits pass, and at Palatino. This will allow the system to be operated in an extremely flexible manner, insuring permanent service in every section of the city.

Under the project, the storage capacity is increased to more than three times the amount now existing, or a total of 54 mil.gal. At Palatino the storage will be increased from 15 to 30 mil.gal.; the Capdevila tank will store

18 mil.gal.; the Güinera tank will have a capacity of 3 mil.gal.; and another 3-mil.gal. tank is to be built on the Mazo Hill to compensate for the peak hourly demand of the Víbora section.

In the Alameda de Paula, close to the harbor, a 300,000-gal. underground tank will be provided to serve the bay area and the ships with either raw or softened water. A special floating station, fed from a booster pump and equipped with two large hydrants of three outlets each, will permit the ships to take on water in a short time. This service will correct one of the greatest inconveniences of Havana harbor; ships are now forced to carry large volumes of water because of the uncertainty of the service.

Havana's present distribution system comprises approximately 500 km. of undersized cast-iron pipes, of which 61 per cent are 3 and 4 in. in diameter; 24 per cent are 6, 8, 10 and 12 in.; 13 per cent are 20, 24, 30 and 36 in.; and only 2 per cent of the mains are 42 in. in diameter.

It is obvious that the serious restrictions in service pipes and mains not only cause high power costs for pumping but also adversely affect the gravity flow and pressure available. It has been truly said by a hydraulic expert that if Havana had all the water in the world at the Palatino tanks the city would not receive any better service, on account of the small diameter of the pipes in its distribution system.

Approximately 60 km. of new mains ranging from 30 to 66 in. in diameter, and 487 km. of smaller pipes ranging from 4 to 24 in., will be installed to correct the present deficiencies of the system. This includes installations in sections of the city where at present there is no distribution system of any kind, consumers being served by trucks and carts at a cost of $50,000 per year. The city is unable to collect any revenue from these sections. The new system will give the city $140,000 additional revenue annually, as well as saving the amount now spent to provide wagon service. In all, the projected distribution network will aggregate better than 600 miles of pipe, as against 300 today.

The entire hydrant system will be revamped to provide approximately 2,000 hydrants for fire fighting purposes. Complete laboratory facilities and disinfecting equipment for the purification and control of the water supply are included in the project.

The Case for the Fire Line Meter

By Eric F. Johnson

A review of the literature and current opinion on fire line metering, developed as a staff activity and published for the guidance of A.W.W.A. members. This survey was submitted to the officers and directors of the Association and by them approved for publication.

GOOD business and good sense dictate the use of the best tools available in operating any enterprise under any circumstances. And in a period when costs have soared and revenues lag far behind, efficiency in operation is more important than ever. Yet, though it is one of the worst sufferers from inflation, the water works industry has virtually ignored one of its newest, most valuable tools—the fire line meter.

What lies behind this lack of acceptance and lack of application is difficult to say. For many years, the development of a satisfactory fire line meter was recognized as one of the foremost requirements of the industry. Each of its imperfect predecessors was hailed by the water works field but fell by the wayside because it could not meet the requirements of the fire underwriters. Now the mechanical problem of metering private fire protection services has at last been solved to the satisfaction of both parties. The new fire service type meters covered by last year's A.W.W.A. specifications (1) meet the needs of the water works superintendent in that they measure accurately the gamut of flows to which they are subjected. At the same time, because they set up no significant obstructions to full fire flows, they have received the seal of approval of the National Fire Protection Assn., which, giving specific reference to two meters of this type, has indicated that they "satisfy all requirements" of the fire underwriters (2). Thus the tool is available and it remains only for water works men to recognize that fact and to put the tool to work in their own interests.

Lack of Acceptance

Apparent from a 1946 survey of 25 scattered water utilities (3), however, is the fact that water works men are far from sold on the advantages of fire line metering itself. Of the 25 utility heads replying, only nine gave an unqualified "Yes" response to the question: "Are you in favor of fire line metering?" Three others gave qualified approval, three offered no opinion and ten said "No." An earlier survey covering the same general question in 1938 (4) disclosed a similar almost even division of opinion on the subject.

In the more realistic realm of practice, this lack of acceptance is still more manifest. A 1947 inquiry into utility private fire protection procedures (5) disclosed that only fourteen of 29 cities—including some of the largest municipalities in the country—

used approved fire line meters at all, and that only one small city among them had adopted the policy of using these meters on all connections. Seven of the cities which reported some use of fire line meters controlled other services by means of a detector check valve. Five cities which did not use the fire service type meters did employ the detector check. But in only seven of the 29 cities polled were flat-rate services actually forbidden. Similarly, a survey in 1927 (6) revealed that only eleven of 33 cities used some form of metering, and a survey in 1938 (7) showed that only 25 of 96 New York cities metered their private fire service lines.

With even those who oppose fire line metering in principle admitting the ability of the new meter to perform its function efficiently, opposition to the practice is now based principally in the field of economics. Yet it is in that field that the proponents of metering fire services develop their strongest case. Unfortunately, although the arguments are based on the same ground, the solution will not yield to simple measurement. So many intangibles are involved and so much weight must be given to local conditions that each case must be considered on its own merits. A brief review of the fundamental considerations, however, should offer a better basis for decision.

The Economic Argument

Of the ten utility heads who reported opposition to fire line metering in the 1946 survey cited above (3), eight opposed the practice for economic reasons, contending that the low revenue yield would not justify the expenditure involved in providing and maintaining the meters. On the other hand, all but one of those who gave reasons for favoring metering justified their position by pointing to the reduction of free or lost water which it effected. It is impossible, of course, to prove either position correct without a thorough investigation in each local situation, but the preponderance of past evidence seems to favor metering.

At present price levels, the approved fire service type meters range in cost between $240 for the 3-in. meter and $1,600 for the 10-in. size. At these prices, there is no question but that water works would have to be assured of considerable additional revenue or reduction in costs to justify the major expenditures involved in providing meters for all private fire service connections. But it is a fact that almost always it is the customer rather than the water works who is required to pay the cost. In all the cases reported in the recent surveys (3, 5), there are only two instances in which the water works pays the entire cost of metering and two more in which the utility shares the cost by providing all meters up to the 4-in. size. Although the 1938 survey of New York State utilities (7) was not as conclusive as this, it is safe to say that, in an overwhelming majority of current cases, the cost of the meter need not be taken into consideration in making an economic justification of fire line metering. And there appears to be no good reason why this condition should not be made universal.

It has been estimated variously (8–10) that industries which install private fire protection systems benefit financially by a 75 to 90 per cent reduction in insurance rates. Can it

then be called unjust to ask those industries to invest a reasonable portion of their cash savings in the protection that yields them the benefit? As a matter of fact if an industry were required to spend every cent of its premium savings in paying for the protection, it would still stand to gain immeasurably from the service provided. Every fire thereby nipped in the bud would involve a tremendous, if intangible, gain. The fire underwriter will indemnify the destruction wrought by the fire, but what of the loss of production capacity occasioned by that destruction, what of the loss of salary to employees thereby idled, and, if the plant should be totally destroyed, what of the loss of business thereby sustained? Basically it is against these irretrievable losses that industry seeks protection when it installs private fire protection devices, and, in view of that fact, it would be foolish to suppose that the traffic would not bear the minor, nonrecurring charge represented by the cost of a meter.

So far as the costs of maintenance and meter reading are concerned, it is difficult to see why they should be significantly greater than current costs of inspection and control, or why they, too, could not be charged back to the customer in whatever guise fire protection charges are currently billed.

Those who vote in favor of fire line metering do so for almost identical reasons. They want to prevent unauthorized use of water through private fire connections and, when such use has occurred, they want to collect payment for it at their established rates. It is not necessary, then, to point out that all nine utility heads quoted as favoring meters in the 1946 survey gave some version of these reasons in telling "why," for even those who oppose the use of meters will grant these advantages. Where the difference of opinion arises is in estimating the dollar and cents net profit or loss to be derived from accomplishing these ends.

It is just here that the impossibility of drawing a general conclusion arises. Few if any water works men will believe, much less admit, that they are losing any significant amount of water through unauthorized connections. Only in a public utility which distributes water free of charge could that situation be condoned on any basis. And where water is being sold, it would be complete dereliction of duty knowingly to permit such a practice to exist. Yet it must exist in practically every community in which some form of metering is not used to control private fire service connections. It must exist, that is, unless human nature has undergone a rather complete metamorphosis in the past two decades —a phenomenon which its behavior on other levels of activity does not bear out.

It was in 1919 that an A.W.W.A. committee on private fire protection presented a 106-page report on the points of issue between the water works man and the fire underwriter (10). And it was as part of that report that the committee presented a review of about half of some 236 reported cases of surreptitious connections. Other instances are legion. The members of the Association, particularly in the early years of the century, spent a great deal of time discussing, castigating and calling for action on the issue (11–26). Some idea of the seriousness of the problem they faced

is indicated by the review of representative cases presented in the Appendix (Cases 1–7). Covering the period from 1903 through 1920, these few cases, which involved all types of industrial installations, cost the utilities involved many thousands of dollars in lost revenue. With the hundreds of other cases reported throughout the field, known losses totaled well up into the millions of dollars.

True, these instances all hark back to an earlier day, but it would be naive to suppose that because there is now no talk, there is now nothing to talk about. Only a few months ago, in Morristown, N.J., Supt. Nelson S. Butera spent considerable time, effort and expense in tracing down a connection that was bleeding one of his mains of 25 to 30 per cent of its capacity (27). That he was able to collect the sum of $9,700 as a fair charge for illicit consumption over the two years that the connection had been tapped did more to convince than deter him in his decision to install fire line meters on all such services. And in alluding to this case in a recent discussion (28), Newkirk also mentions two other contemporary instances (Case 8, Appendix).

In bringing these cases to bear on the point, it should by all means be pointed out that the majority of such unauthorized connections are not made with the intent to defraud. But that fact in itself, unless fire lines are metered as a routine matter, helps to hide violations, for not many utility officials are inclined to act on the theory that their customers are guilty until proved innocent. Perhaps the best example of the fact that responsible industry officials are not ordinarily aware of the existence of unauthorized connections is a case reported in 1929 by H. E. Beckwith (29) in which the water commissioner who instigated the investigation was the majority owner of the industrial property proved to be stealing water from the system. Whatever the circumstances of origin, however, it is not the guilt involved but the existence of unauthorized use which deprives the water works of revenue and reduces the effectiveness of the fire protection system itself.

Instances such as those mentioned above, together with the evidence revealed by utilities which have decided to install some form of metering, clearly suggest that profit rather than loss will result from the adoption of metering. Two cases in point are those of Worcester, Mass., and Lockport, N.Y., each of which, in a 1908 test, placed meters on seven of its private fire lines. As a result, Worcester was able to reduce its pumpage by 750,000 gpd. and Lockport by 1 mgd. (21, p. 558). And 30 years later the same type of experience was reported by Cook (8) in the description of two cases in which the cities involved estimated their losses through illegal use at $360,000 and $200,000, respectively. (Cases 9 and 10, Appendix.)

It is for these same reasons that it appears unwise to qualify adoption of metering. Many municipalities operate on the principle that fire line meters should be installed only where unauthorized connections have been found or where the private system is not closed or sealed or controlled in some other way. But experiences such as those cited have shown that many unauthorized connections remain unfound in spite of all inspections and that systems often become unsealed, unclosed or uncontrolled through either

error or ingenuity. Worse than locking the barn door late, this is hiring the policeman only after the criminal has been convicted.

In considering the costs of supervising fire line meters, those who favor metering are wont to point out that the savings realized in plugging up only one or two such gaps in the distribution system will pay for a lot of meter reading and maintenance—will even pay for a lot of meters if it is felt necessary to provide them at utility expense. And where detection of unauthorized use results in discontinuance of, rather than payment for, that use, water works men feel that they can credit their meters with an economical provision of additional system capacity.

Other Arguments

Outside the field of economics a few opponents of fire line metering still base their arguments on the morality of the matter (3). It is the duty of the water works, they say, to provide water for fire protection; private fire protection systems are merely an extension of the public system which should be encouraged because they augment the public equipment at virtually no cost to the city and which, by placing protective devices where they can be used in the incipient stages of fires, actually save water.

No one will contest the moral obligation of the water utility to provide water for fire protection; and, as a matter of fact, none of the utilities questioned in the above surveys, whether they use meters or not, makes a charge for water used in extinguishing fires. But that point appears to have little bearing on the real question. Those who meter private fire protection lines do so to prevent misuse, not to penalize proper use. Thus, by setting up meter controls, a utility can actually discharge its moral obligations much more efficiently in making certain that a full supply of fire protection water at full pressure will be available when it is needed. In the reduction of insurance premiums and in the less tangible fire control benefits, there appear to be as strong reasons for installing private fire protection devices as there are for extending the public water supply system into private homes through plumbing, so that the additional encouragement afforded by an unmetered supply cannot be considered vital to the decision. As a matter of fact any plant owner who hesitates to install sprinklers because the water system connection must be metered is probably less interested in the fire protection or prevention provided than in the opportunity it gives him to appropriate some free water.

And on ethical grounds the proponent of fire line metering has a still stronger string to his bow, for only through metering can an equitable distribution of costs be assured. The actual proportion of water works cost attributable to private fire connections varies with each locality, and the variation in methods and amounts of charges for those connections is more limited only because a great many municipal water utilities make no charge for fire service.* To burden regular consumers with an inequitable share of the costs by poorly conceived fire protection charges is bad enough; to require

* Of some 700 U.S. cities which replied to a recent questionnaire on private fire protection practices, approximately 60 per cent reported "no charge for fire service" (30).

them to carry the entire load by making private fire systems free riders is even worse; but it is the crowning inequity to add to their bills the cost of water surreptitiously used or wasted through unmetered private fire service connections (7, 10, 31, 32).

The only really equitable—and therefore ethical—method of charging for water service involves metering all services and allocating charges on the basis of consumption together with a "readiness-to-serve" charge based on the type of connection through which a customer is served and related to the actual cost of that portion of plant capacity dedicated to his service. It remains a fact, of course, that many communities will have to get along with flat rates for some time to come. But even the worst flat rate makes some attempt at being equitable by classifying service, and, unless private fire connections are subject to some form of meter control, there is no telling what type of service is actually being rendered through them.

Conclusion

Taking these facts and arguments into account, it is not difficult to conclude that it is both good business and good sense to meter all private fire protection services. Such a conclusion appears logical whether or not other types of services are metered, whether or not a charge is made for private fire service and, if one takes seriously enough his obligation to provide full fire flow at full pressure, whether or not any direct charge is made for water service.

Insofar as it is good business practice to account for all water which enters the distribution system and insofar as it is good sense to charge for all water provided to a customer, it is both good business and good sense to take advantage of the best tools available for those purposes. And even if the adoption of such tools is financially or politically impossible in any given community at any given time, there appears little good reason why a water works man should not favor even a losing cause when it is a good one.

Actually if you grant the necessity of accounting for the water you put into your distribution system, if you grant the desirability of allocating your costs of operation equitably among your customers and if you grant the importance of maximum efficiency in your fire protection system, public or private, you are in effect favoring fire line metering. And if you do favor it, now—with a satisfactory meter available—would appear the proper time to do something about it.

APPENDIX

Cases of Unauthorized Use Through Private Fire Connections

1. In 1903, one water department found that a packing plant had been watering 4,000 head of cattle for four years through an unauthorized connection to its private fire lines. Loss in revenue to the department was estimated at $5,000 (13, p. 444).

2. In the same year, another department discovered that a factory which was purportedly pumping its own industrial supply directly from a river had to shut down its boiler for lack of water when the department began repairs on the main from which

the factory's private fire lines were supplied. Investigation revealed that the factory had been appropriating water for its 150-hp. boiler from the line for a period of two years (22, p. 12; 23, p. 66).

3. In 1908, the Richmond, Va., Locomotive Works was presented with a water bill of $4,026 as a result of the discovery that the plant had been wasting enough water through an unreported leak to reduce pressure on the 10-in. fire line some 2½ psi. (21, p. 558).

4. In 1911, one superintendent decided to make a check on two factories which claimed to be using no water through their private fire lines. When he attached meters to their connections, he found that one registered usage at the rate of 200,000 gpd., the other at about 22,500 gpd. (24).

5. In 1914, the Philadelphia water department reported the discovery that one of the city's newspaper plants had tapped a 2-in. connection on its 4-in. fire line to supply water for its type foundry operations (25).

6. In 1919, the A.W.W.A. Committee on Private Fire Protection Service, in its long list of cases, mentioned two unusual ones: In one city, it was found that a factory sometimes took the entire public supply during the night, drawing it surreptitiously through an unmetered fire line attached to gravity-fed street mains, thereby leaving the rest of the community without fire protection. In another city, the water department received a request to substitute a 4-in. line for a 2-in. one that had been in service for only a year. Checking the request when he was advised that the 2-in. line was inadequate, the superintendent found that the plant had been using for other purposes all the water the line would deliver under 80 psi. pressure (10).

7. Later, the city of Northampton, Mass., reported the loss of about $1,200 per quarter through an unmetered fire line to the Mt. Tom Sulphite Co., where workmen filled a large tank twice a day through a connection to the fire line, preferring to use the public supply at 90 psi. to the company's private supply at 30 psi. And Newark, Ohio, was successful in a suit to collect from a plant which had been taking 900,000 gpd. for several years through an unauthorized connection to the unmetered fire line (26).

8. During 1947, at Elizabeth, N.J., a community which has only 43 private fire service connections, two instances of misuse were brought to the atttention of the Water Board. In one plant, a plumber connected a washroom tap to the automatic sprinkler system; in another, a manufacturer drew his full supply from the fire system while his private well supply was being reconditioned. Both violations were discovered by the use of meters (28).

9. In one city where the greatest possible care was taken to prevent illegal use of water through the numerous unmetered fire lines, a test of the success of the precautions was made by metering ten of the lines. In the first month it was found that four of the ten plants had used water at a rate of 75 mil.gal. per year. If the same percentage held true for the remainder of the lines, the department's loss would be more than 2 bil.gal. per year, or approximately $360,000 (8).

10. In another city, which metered all of its 300 private fire lines, the meters were not read, on the theory that the lines were used for fire pro-

tection only. A check-up occasioned by the large percentage of unaccounted-for water revealed that at least 40 per cent of the 300 customers were using the fire lines for general supply purposes. The loss was estimated at more than 1 bil.gal. per year, or almost $200,000 in revenue (8).

11. Not many years ago, in Jersey City, N.J., the water superintendent noted that consumption records for a large department store equipped with hydraulic elevators were very low. The store manager assured him that all water being used was drawn through the regular metered connections. But when a check was made by closing all visible valves around the store except those on the metered lines, the elevators and other water-fed equipment immediately ceased functioning. Proceeding on the same basis, the superintendent made a similar check on one of the large railroads which terminated in Jersey City and was greeted by a loud protest from the company, which was unable to obtain water for its locomotive tenders. In both cases fire line meters were installed at the expense of the consumers and revenues increased significantly.

12. Just this year, in one of the large mills at Manchester, N.H., the local water department discovered a 4-in. connection to a 6-in. private fire service line which was feeding toilets on five floors of the building. The unauthorized use involved had gone undetected for several years because the connection to the sprinkler line had been made in the basement of the structure.

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Financing Municipal Water Works Improvements in Indiana

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A paper presented on April 21, 1948, at the Indiana Section Meeting, Lafayette, Ind., by David N. Brewer, Attorney, Ross McCord Ice & Miller, Indianapolis, Ind.

THE two general methods of financing municipal water works improvements are the same as those used by a private citizen when placing a new roof on his house or installing a new furnace. The roof or furnace may be paid for from accumulated savings or the necessary money may be borrowed with the agreement that the loan will be repaid out of future earnings. In the first instance, the person who sells the roof or furnace is glad to take the money and asks no questions. In the second instance, however, anyone who considers loaning money inquires into the borrower's ability to repay the loan. If it is doubtful that he can repay it within a period dictated by business judgment, the money will not be forthcoming, regardless of how badly the improvements may be needed. To an even more marked extent, this situation underlies the financing of municipal water works improvements.

Since most municipal water works improvements involve the expenditure of sizable sums of money, it is not usually feasible to pay for all of them out of funds on hand. As a result, nearly all municipalities must borrow the money, usually by the issuance and sale of bonds. Stripped of legal phraseology, a bond is nothing more than a written promise to repay a loan, with interest, on a certain date. Bonds also indicate the security which is pledged for the repayment of the loan and interest. If the bonds pledge the credit and property of the municipality and are to be paid out of taxes levied upon the property, they are styled "general obligation" bonds. Those payable only from the income—or revenues—of the water works utility are called "revenue" bonds.

Usually either general obligation or revenue bonds may be issued to finance water works improvements. The Indiana state constitution provides that a municipal corporation may borrow money in an amount up to but not exceeding 2 per cent of the net assessed valuation of the property located within its boundaries. General obligation bonds come under this debt limitation. For example, a city or town having a net assessed valuation of $1,000,000 may issue and sell a total of not more than $20,000 in general obligation bonds, assuming that it has no other outstanding debt. Similarly, a city with a net assessed valuation of $10,000,000 may issue general obligation bonds in an amount not exceeding $200,000. Of course, as the bonds are paid off, the city or town can issue additional bonds up to the 2 per cent maximum. This power to incur debts

and pay them out of taxes constitutes the principal source of funds with which the municipality pays for various *general* improvements, such as the construction or improvement of public buildings and the like. For this reason most municipalities find it undesirable to exhaust the debt allowance for utility projects. Moreover, the amount of general obligation bonds which can be issued—or what is sometimes called "debt leeway"—is usually insufficient to cover the cost of the improvement project.

Indiana Legislation

The first water works revenue bond statute in Indiana was passed in 1921, and the State Supreme Court has held that bonds payable solely from the revenues of the water works and not from taxes do not constitute an obligation of the city within the constitutional debt limit. Although there is no constitutional or statutory limit on the amount of revenue bonds which may be issued, there exists what might be considered an economic limit on the amount which a given municipality can sell. For example, there is no legal prohibition against a town with a population of 500 and a net assessed valuation of $250,000 offering for sale $300,000 worth of water works revenue bonds. It is probable, however, that the town will receive no bids for the purchase of the bonds. Although conceivably it might be argued that such a water works would have sufficient income to pay for operation, maintenance and depreciation, as well as the principal and interest of the bonds, the rates and charges for water would have to be exorbitant or an improbable increase in water consumption within a few years would have to be predicted. Either condition would make the picture doubtful and unattractive. It is not intended to give the impression that this economic limit applies only to the smaller communities; it applies to all municipalities. It is an intangible concept and there is no mathematical formula for the determination of this limit. No two investment houses would agree on what the limit is for a given municipality. It will vary even between two municipalities with identical population and property valuation figures. One element involved is the character of the community and whether it is growing, static or retrogressing. Another is the nature of the water usage and the proportion of revenues received from the different types of users. The economic limit is approached when there is a feeling that a given improvement program is too ambitious and expensive in relation to the size and character of the municipality.

This paper concerns the financing of *improvements* to water works rather than the initial building or purchase of a complete water system. In Indiana, there are different laws under which improvements are financed and the particular statute applicable to a given municipal water works usually depends on the manner in which it was originally built or acquired. If the water works was built or acquired after 1933, a 1933 amendment to the Spencer-Shively Act of 1913, which established the Indiana Public Service Commission, may apply. If the water utility was municipally owned prior to 1933, it should be determined whether it was purchased under Chapter 96 of the Acts of 1921. The procedure for improving water works so purchased is usually governed by this law as supplemented

by Chapter 88 of the Acts of 1929, which was in turn amended by Chapter 287 of the Acts of 1947.

The largest class of municipal water works in the state, however, might be said to have, like Topsy, "just growed." In other words, the acquisition was probably financed about the turn of the century, or often long before that time, directly from taxes or other funds, or from general obligation bonds of the city or town. Extensions were paid for by earnings or sometimes by contributions from water users. It is not uncommon to find that no one knows exactly when or how a water works was originally built or acquired, except an old resident who remembers it was "back around the 1880's." For water works in this class, improvements are usually financed under Chapter 155 of the Acts of 1929. The manner in which the water works was originally constructed or acquired must, however, be accurately determined.

In one town which was contemplating improvements to its water works, the city officials did not learn the utility was not municipally owned until a suit was filed by the Attorney General to forfeit the water company charter for failure to submit annual reports as a private corporation. Nearly all of the preferred stock of the water company had been redeemed, with the remaining shareholders unknown; the common stock was held by the town, which had paid no rent on the water works lease for a number of years. Because no revenue bonds could be issued for improvements to a water works not owned by the municipality, the Attorney General's suit proved beneficial, since it enabled the court to dissolve the water company and grant the town title to the utility.

If a utility is operated as a water department by an independent board of trustees under Chapter 235 of the Acts of 1935, improvements must usually be financed under the provisions of this statute. If, in addition to financing the improvement, the program calls for the refunding of outstanding revenue bonds or other debts payable out of the revenues of the water works, the financing will be governed by Chapter 206 of the Acts of 1937. Furthermore, there is one city in Indiana which has a taxing district type of law for its water works. The determination of the particular law under which the improvement must be financed and the technical requirements of that law are really matters for the city or town attorney and the bond counsel who is to approve the bonds.

Except for the Spencer-Shively Act amendment and the taxing district law, the above statutes on financing improvements require that the utility's gross revenues be allocated to three accounts: operation and maintenance; depreciation; and bond and interest redemption. The approval of the Public Service Commission is also required, and, under certain of these statutes, the commission must find and certify that the income and revenues of the water works are sufficient to provide for operation and maintenance, depreciation, and payment of the principal and interest on the bonds as they come due.

Revenue Bonds

The laws provide that fixed proportions of the total gross revenues of the utility be allocated to each of these three accounts, although no specific percentage for each account is named, since this obviously depends upon the situation in the particular water works. For example, the cost of operation and

maintenance will not be the same for two given water works. Moreover, because the income from the rates and charges for water varies from one municipality to another, operation and maintenance costs will not represent the same percentage of the gross income of every water utility.

As an illustration, let it be assumed that the operating records of a certain water works show that 60 per cent of the gross revenues is required annually for operation and maintenance and 5 per cent is adequate for depreciation. It is also assumed that these percentages will apply in future years. Thirty-five per cent of the gross revenues is then available each year for servicing bonds to be issued to finance improvements. Only this 35 per cent can be considered in determining the amount of revenue bonds which can be issued, and, unless there are other funds on hand, the amount of bonds which can be issued will, of course, limit the size of the improvement.

It is not sufficient, however, for this 35 per cent of gross just to meet the annual principal and interest requirements of the bonds. The statutes provide that all municipal bonds, whether general obligation or revenue, must be sold for not less than the par value at public sale on a bid interest rate. The best bidder is the one who offers the municipality the lowest actual interest cost—determined by computing the total interest cost on the bond issue at the bid interest rate and subtracting the amount of any premium which is also offered. If the bonds were advertised for sale with the available revenues barely covering the principal and interest, no bids would be received. If for any reason the income of the water works decreased, there would be a default in the payment of the principal or interest of the bonds, since the revenues would not be sufficient. A large water user might move away from the city or his establishment might burn down; a shrinkage or partial failure of the water supply might cause a curtailment in water usage and a corresponding reduction in revenues. Because of these contingencies, bond buyers require that surplus revenues be available for debt service over and above the bare principal and interest requirements of the bonds. This is called "coverage" and is a margin of safety or cushion.

A "coverage of 150" means that the revenues available for debt service, over the period the bonds are to be outstanding, will be 150 per cent of the amount of principal and interest. At present, for a water works revenue bond issue to attract the favorable attention of prospective buyers, the coverage should be at least 125 or better. It follows that the greater the coverage, the more bids the municipality will receive and the lower the interest rate will be. It can be seen, however, that the necessity for coverage considerably decreases the total amount of bonds which the fixed percentage of revenues will support. A reputable investment house engaged in reselling bonds to its customers is in an analogous position to a merchant who sells goods to regular customers. A discriminating merchant will not sell shoddy merchandise if he values his customers' trade and desires to stay in business. Bonds with poor coverage might be termed shoddy merchandise—and it will generally be found that investment houses are much more discerning than any merchant.

A further factor to be considered is the period of years over which the bonds are to be outstanding. The

shorter the period, the greater must be the revenues available for payment. A bond issue of $200,000 maturing over a period of ten years requires an average of $20,000 each year to pay the principal alone; if the period is 30 years, approximately $7,000 is required annually. This is exclusive of the interest, which may amount to as much as one-fourth to one-half of the amount of the bond issue. In the present bond market the shorter-term bonds are more salable. As a result, the period during which the bonds are to be outstanding should be as short as possible, consistent, of course, with the revenues of the water works and the previously mentioned coverage requirements.

In comparison with past years, interest rates on municipal bonds are low. When money for investment is dear interest rates are high, and when money for investment is plentiful interest rates are low. No one knows how long the current situation will continue, however. Because of this, investment houses find short-term bonds easier to sell in the present market than long-term issues. In re-offering the bonds for sale to its customers, an investment house will sell the short-term bonds of an issue at a premium but may be forced to sell the long-term bonds at approximately par, or sometimes even at a discount. This fact, naturally, is reflected in the computation of the bid for the bonds and the resulting over-all interest cost to the municipality.

Estimation of Revenues

In estimating the amount of future revenues which will be derived from the water works and which will be allocated to the three accounts—operation and maintenance, depreciation, and bond and interest redemption—there is no objection to making allowance for future increased water usage if there is a reasonable basis for estimating an increase in a particular locality. Some of the factors forming such a basis include a steady growth in the population and an increase in the number of water users during the past several years; the favorable location of the municipality from the standpoint of attracting new industries and a resulting increase in the number of domestic and industrial users as demonstrated by past expansion; in short, all of the various factors which go to distinguish a growing community from a static one. As another example, in communities where the water supply has in previous years been very limited and water usage, particularly during the summer months, has necessarily been restricted, it is reasonable to estimate an increase in consumption, and a corresponding increase in gross revenues, when the proposed improvement consists of providing an adequate water supply. Such estimated future increases in gross revenues, however, should very definitely be conservative and must have a sound factual basis in the conditions in the particular municipality. Bond buyers do not rely on the predictions of the local chamber of commerce. A showing of "coverage" on a bond issue which is based almost entirely upon speculative future increases in gross revenues does not deceive the investment houses. Bond buyers give a great deal more weight to past performances than to future predictions.

Assuming that the water works is efficiently operated, there is only one way in which a municipality can obtain sufficient revenues to service the bonds and provide the necessary coverage. The rates and charges for water and

the amount of fire hydrant rentals must produce gross revenues which will be sufficient to provide for operation and maintenance, depreciation, principal and interest payments, and the coverage necessary to enable the bonds to be sold. If the rates and hydrant rentals produce only enough gross revenues to operate the water works, they must be increased before the bonds are sold or the municipality must forego the improvement. Bond buyers view favorably a pledge by the municipality to collect fixed minimum fire hydrant rentals that are substantial during the period that the bonds are outstanding. Fire hydrant rentals are payable from taxes and hence represent a constant income for the water works on which bond buyers can depend.

There is no painless magic in financing water utility improvements by the issuance of revenue bonds; the inhabitants of the municipality must pay for the improvements in the rates and charges for water and fire protection; the people are, in a sense, merely buying the improvements on the installment plan from an informed seller who will make certain that they have the capacity to meet the installments. Since all of Indiana's water works statutes except two preclude the lender from taking over and selling the water works like private property on failure to repay the loan, the inhabitants of the municipality must undertake to pay the rates and charges necessary to meet the cost of the improvement or else curtail its scope to a point where it can be financed.

It is only common sense for the officers of the municipality and their engineers to determine the ability of the municipality to finance the desired improvement. It obviously is a waste of time and money to design an improvement which the municipality is unable or unwilling to finance. The Public Service Commission would not approve such a project, and, even if it did, the municipality probably could not sell the bonds at all and certainly not to advantage.

Refinancing

Another aspect of financing municipal water works improvements through revenue bonds arises when it becomes necessary to issue bonds for an additional improvement while previous bonds are outstanding. This may be done through the issuance and sale of either junior revenue bonds or refunding and improvement bonds. In comparison with real estate transactions, a junior bond issue is somewhat analogous to a second mortgage on the same property. A refunding and improvement bond issue is like borrowing sufficient money from one bank on a new mortgage to pay off an existing loan and mortgage at another bank and still have funds left over for contemplated new improvements. Whether or not refunding or junior bonds can be issued depends upon the provisions of the ordinance authorizing the issuance of the outstanding bonds. Some of the old ordinances authorizing revenue bond issues in past years did not permit the redemption of outstanding bonds prior to maturity and prohibited the issuance of junior bonds. These provisions were often considered necessary in order to make the bonds salable. It may also have been felt that no further improvements would be necessary during the period over which the bonds would be outstanding and that the surplus revenues of the water works would never be sufficient to redeem the

bonds prior to maturity. The experience of certain municipalities has demonstrated that all revenue bond ordinances should provide the right both to redeem the outstanding bonds and to issue junior bonds.

Refunding and improvement bonds bring a better price to the municipality in the market since they constitute a first charge against the revenues of the water works. In other words, the old bonds are redeemed from the proceeds of the new bonds so that the new bonds are the only ones outstanding. Junior revenue bonds, being a second charge against the revenues as long as the old bonds remain outstanding, will have to be sold at a higher interest rate than first-charge bonds. It might therefore seem that the municipality should always issue refunding and improvement bonds rather than junior bonds. Outstanding bonds are rarely callable at par, however. An investor is not attracted by a bond bearing 3½ per cent interest which can be taken away from him in a few years merely by giving him back his money. He has usually paid more than the face value of his bonds when he purchased them from the investment house, and some time must elapse before he begins to realize any real income from his investment. As a result, it is almost always necessary to provide in the ordinance for call rates, or redemption premiums, on the bonds in order to make them salable. Call rates are usually expressed as percentages, but sometimes as a redemption price, such as 106, 104 or 102. For a $1,000-denomination bond, a call premium of 6 per cent, or a redemption price of 106, means that the municipality will have to pay $1,060 to redeem the bond. Where the bonds are issued in serial maturities, it is customary to provide for them to be callable on certain interest payment dates in inverse numerical order—that is, to work from the long-term back to the short-term bonds. Redemption in this manner has the effect of shortening the period in which the entire bond issue is outstanding, as well as reducing the total interest cost to the municipality, if the bonds are being redeemed out of surplus revenues and no refunding is involved. The call rates are usually stepped down over the period in which the bonds are outstanding from a high call premium in the event of redemption in the earlier years to a low premium in the later years. If refinancing may be necessary within a relatively short time after issuance, the bonds should be made callable on any interest payment date after issuance, or they may be made noncallable for a short period, such as the first five years after issuance. The call premiums which should be established in the bond ordinance depend upon the market at the approximate time the bonds are to be sold. Call rates which are too low will affect the bids for the bonds and those which are too high are obviously not to the advantage of the municipality. Whether it is wiser to issue junior bonds or replace the outstanding bonds with refunding and improvement bonds depends upon the facts in the particular situation and no rule-of-thumb can be stated. Generally, however, it is better to refund the old bonds if the additional improvement will require a sizable amount of bonds, and to issue junior bonds if the additional improvement requires a relatively small amount of bonds.

Call rates are useful in other situations besides refinancing. Redemption provisions are primarily intended

to permit the application of surplus revenues to the retirement of a debt prior to the time it becomes due. This is particularly important in electric utility revenue bonds since the net earnings available for debt service are greater for such a utility than for a water works. However, this aspect is equally important in any utility which will have sufficient surplus revenues available to call bonds prior to maturity.

In discussing the financing of additional improvements when there are outstanding bonds, it has been assumed that the improvements cannot be paid from funds on hand. It will be recalled that most of Indiana's bond laws require the allocation of fixed proportions of the gross revenues to three accounts. Under the statutes, the depreciation fund is more than a bare account for straight-line depreciation on the existing plant and equipment. The laws also permit the use of funds in the depreciation account for improvements, extensions and additions. Obviously, it is least expensive for the municipality to pay for improvements out of accumulated revenues, since the interest cost on bonds is avoided. If the municipality can pay even a portion of the improvement cost from accumulated revenues, the size of the bond issue necessary for the balance of the cost can be reduced and savings in interest cost effected to that extent. The fact that a municipality can pay part of the cost of an improvement from accumulated funds on hand improves the overall picture and helps the sale of the bonds for the balance. Whether the refinancing of additional improvements is involved or not, it is desirable to pay all or a portion of the cost of any improvement from funds on hand. Of course, the rates and charges for water must produce sufficient gross revenues to permit such an accumulation of revenues in the depreciation account.

Efficiency of Operation

Another factor which is given considerable weight in the sale of revenue bonds to finance improvements is the caliber of the management of the utility and the efficiency of its operations. In some plants, income and expenses are handled lackadaisically. Little attention may be paid to the expenses of the water works in relation to the revenues, and the collection of rates and charges may be carried on in an indifferent and half-hearted manner. Several years ago, in a hearing before the Public Service Commission on a proposed rate increase and the issuance of revenue bonds for a badly needed improvement in a town, it appeared that the amount of delinquent charges was quite large. There was a good deal of local opposition to the project and the opposition had employed a local attorney. On cross examination of the town officials who were witnesses for the project, it developed that practically all of the members of the administration were delinquent in their water bills and that the three town officials owed from $50 to $100 each. Needless to say, the Public Service Commission disapproved the petition for an increase in rates, but, even had the project gone through, a prospective bond buyer investigating the local situation would have come to the sudden conclusion that he could readily find better investments elsewhere.

The bookkeeping has sometimes been so incompetent that it has been almost impossible to determine whether there are any net operating revenues to sup-

port a bond issue. Improvements, extensions and additions in the immediately preceding years have been paid from revenues and placed on the books as "general expense," "supplies" or "repairs," with the result that the financial data makes it appear the water works has no net operating revenues or even operates at a deficit.

Conclusion

The statements made in this paper have of necessity been general in nature. When applied to an improvement program of a given municipality, many of them would require qualification. It is not possible in a revenue bond issue to take a blank form and merely fill in the name of a municipality, a description of the improvements, the amount of bonds and maturities, and the estimated percentages for allocation to the three accounts. If the bonds are to be sold to advantage, or sold at all, the financial data must be worked out in detail and the bond proceedings carefully tailored to fit the improvement program before going to the Public Service Commission and before offering the bonds for sale. Records of income and operating expenses for the past three to five years should be analyzed and future income and operating expenses should be carefully estimated. If the financing program requires an increase in rates and charges, a rate survey should be made to determine what rates and charges should be increased to produce the increase in gross revenues needed to finance the improvement. As previously emphasized, it must be demonstrated that there will be revenues available to pay the bonds and interest and provide sufficient coverage to enable the bonds to be sold.

Possible Hazards Due to Cadmium-coated Pipe and Fittings

By Leo V. Garrity

A contribution to the Journal by Leo V. Garrity, Asst. Gen. Supt., Dept. of Water Supply, Detroit.

THE electrodeposition of cadmium has developed rapidly in the last 30 years, because when in contact with steel it forms a protective galvanic couple, superior in malleable fittings to that provided by zinc. The acid and ammoniacal solutions originally used have been found unstable, and they produce a crystalline, porous deposit. A complicated sodium-cadmium-cyanide solution is now largely used, with and without the addition of other agents. Cyanide solutions are relatively stable, and they deposit a compact, crystalline coating of reduced particle size, with a luster pleasing to the eye.

Immediately after the steel has been plated, it has to be rinsed in cold water, followed by a bath of hot water approximately at the boiling point. This rinsing is believed to remove all traces of cyanide, which otherwise would produce darkly discolored—and usually unmarketable—products.

Toxicology of Cadmium

Despite its usefulness as an anti-corrosive coating, the toxicity of cadmium makes it unacceptable for many uses, such as the coating of food containers and implements, water pipe or fittings. In its dissolved state, the metal is a powerful emetic and a gastro-intestinal irritant. In the form of its soluble salts, it can readily cause both acute and chronic poisoning. A search of the literature and other source material fails to reveal a death resulting from cadmium taken orally, although several serious sicknesses and even deaths have been recorded from cadmium oxide entering the body through the respiratory system, as a result of the improper melting of the metal.

Only traces of cadmium have been found present in soils, and therefore it would not occur in appreciable quantities in plant products. As far as can be determined, it has not been found in human tissues, nor in those of other animals.

Whether or not the toxic effects of cadmium are cumulative in the same fashion as those of lead, when taken up by the human system, is uncertain. There is some evidence that as little as 14.5 mg. of the metal, taken orally, caused nausea and vomiting, and that as much as 326 mg. did not cause death.

Possibility of Contamination

Table 1 shows the amount of cadmium per square inch of plated surface for various thicknesses of coating. It has been stated that the average coating is 0.0002 in. thick, which means that there is 28.4 mg. of cadmium per square inch of plated surface.

Cadmium is readily attacked by almost all acids, weak and strong, and for this reason is particularly dangerous

in contact with foods. In one history of cadmium poisoning involving 208 men, it was found that lemonade, after 1½ hours in cadmium-plated receptacles, contained 100 ppm. of cadmium, and at the end of 24 hours, 250 ppm. There are also records of poisoning resulting from the ingestion of a number of foods and drinks which were in contact with cadmium or cadmium-plated containers. Contamination has occurred in punch, iced tea with lemon, fruit juices, coffee, popsicles containing fruit acids, and both lemonade and gelatin mixtures containing tartaric acid. The contamination of the coffee was noteworthy because the kettle it was kept in was not plated, but had merely been treated earlier with hydrochloric acid containing cadmium.

TABLE 1

Amount of Cadmium Present in Various Coatings

Thickness of Plate *in.*	Amount of Cadmium *mg./sq.in.*
0.00005	7.1
0.00010	14.2
0.00015	21.3
0.00020	28.4
0.00030	42.6
0.00050	71.0

In neutral solutions, or in aqueous solutions similar to drinking water in mineral content, it appears that corrosion rates would depend upon the amount of oxygen present. It is possible, however, that drinking water in contact with cadmium-plated pipe or fittings might become contaminated as a result of a number of causes. The accidental introduction of small amounts of acid into a system, such as might result from the careless use of hydrochloric acid for pipe cleaning, could have serious consequences. Furthermore, it is considered possible that stray-current electrolysis might cause appreciable quantities of the metal either to enter into solution or to be carried as a relatively unnoticeable white suspension in water. Similar effects might be produced by accelerated attack in hot water systems or in water containing metaphosphates or other chemicals, or even by normal rates of attack, such as might occur in very soft waters with a high carbon dioxide content, or in zeolite-softened waters. Moreover, significant quantities of cadmium might be dissolved by water after long periods of contact, such as could occur in service pipes when the occupants of a dwelling are away on vacation. The performance of mechanical work on old cadmium-plated fixtures might also present a hazard by dislodging products of cadmium corrosion in toxic quantities

At present, it does not seem to be known whether any added danger attends either the possibility of incomplete cyanide removal during the rinsing bath which follows electroplating or the fact that cadmium combines directly with chlorine, iodine and bromine when placed in solutions of those elements.

Existing Controls

No accurate information on the degree of risk which might be involved is available, however, and until extensive studies on the subject have been conducted, opinions must be considered largely speculative. It is of interest to note, however, that local agencies in such cities as New York and Detroit have considered the danger grave enough to regulate the use of cadmium and cadmium plating. The New York Dept. of Health has ruled that the use of cadmium is dangerous and forbids it in food utensils and equipment. In

Detroit, the local plumbing code does not permit the use of cadmium-plated fittings, appurtenances or pipe, and the Dept. of Health and the Dept. of Building and Safety Engineering are particularly vigilant to see that the code is not violated.

A discussion of the problem with representatives of the Detroit agencies revealed that they are thoroughly aware that isolated fittings in water services, such as unions, bushings or ells, may not present a health hazard. Because of the toxicity of the metal, however, and because there is little agreement on such questions as whether its effects on the body are cumulative or what degree of solubility can be tolerated in water intended for human consumption, the Detroit agencies feel that it is safest to ban the material entirely.

One supplier of cadmium to the electroplating trade, the Udylite Corp. of Detroit, advises its customers in one of its publications (1) that "as a rule, it is wise to use some other coating, such as tin, when food and drink are involved."

Conclusions

There is so little evidence of the actual hazard presented by the use of cadmium-plated metals in water distribution systems that the projection of studies on this subject might well be fruitful. There seems to be little demand for such materials by water works men at present, although under the current uncertain conditions of supply it is possible that cadmium-coated fittings may be available when galvanized fittings are not. Because cadmium gives better protection to malleable fittings than zinc, any definite finding that cadmium is safe in water works service would, of course, be welcome news.

Acknowledgment

Appreciation is due to C. C. Ruchhoft, Head Chemist of the U.S. Public Health Service, for making available his knowledge and experience on this subject.

Reference

1. Anon. Toxicology of Cadmium. Tech. Bul. 27–B, Udylite Corp., Detroit.

[*Note: This article was developed as a result of suggestions occasioned by some correspondence of the A.W.W.A. with the Detroit Board of Water Commissioners and the Michigan Dept. of Health. Examination of the possibility of instituting a research program has been made, and it has been learned that there is sufficient interest in the subject for such a program to be instituted in the state of Michigan under university auspices.*—Ed.]

Design of Long-Span Self-supporting Steel Pipe

By Gairald H. Garrett

A paper presented on May 6, 1948, at the Annual Conference, Atlantic City, N.J., by Gairald H. Garrett, Vice-Pres., Thompson Pipe and Steel Co., Denver, Colo.

THE use of ring girders for supports in long-span steel pipelines has given pipe designing engineers a new and valuable tool with which to work. Rigid ring girders at points of support prevent any distortion of appreciable magnitude in the pipe. Since the pipe is then held to a circular shape at the points of support, it naturally remains circular throughout its length between the supports. A tubular shape, in which distortion is prevented, makes a relatively good beam as far as bending and lateral strength are concerned.

It is believed that the use of ring girders in pipeline construction was first introduced into the United States in the early 1930's by Herman Schorer. The first design of this kind was originally employed in Sweden in 1911. Prior to the use of ring girders on pipe—and even today—many pipelines were designed to be cradle supported, with the pipe usually being allowed to move freely back and forth in the cradles. In addition to the cradles, some designs call for rings to be attached to the outside of the pipe at each end of the cradle. Ample space is provided between the ends of the cradles and the rings so that the pipe is free to move back and forth, thus making possible longer spans. Much greater spans, however, can be had with ring girder construction. It is the purpose of this paper to try to give enough information on ring girder construction for engineers who are not now familiar with it to make use of this type of self-supporting pipe design.

Long-Span Installations

The Thompson Pipe and Steel Co. has materially influenced the trend of long-span pipe design. To the author's knowledge, the only spans in the world over 100 ft. in length are located in the states of Colorado, Wyoming and Montana. It is believed that there are many other places in the United States where spans of these lengths could be used economically.

The first 100-ft. span to be built was constructed in 1937 to carry raw sewage across the Platte R. at Denver, Colo. The pipe, which is 78 in. in diameter and is lined with coal-tar enamel, consists of two spans of 105 ft. each. Figure 1 is a picture of this pipeline. The rings shown on the pipe along the spans were placed there to hold the pipe round during construction. It has since been found that rings of this kind are not necessary, as they add no strength to the pipe during operation.

Because of its unusually long spans, this installation has attracted the attention of engineers from all over the world. A number of longer pipe spans have since been constructed, but none

has created the interest that this first long-span pipe did.

Figure 2 shows a smaller long-span pipe crossing a road near Crowheart, Wyo. The center span on this pipe measures 88 ft., and the two end spans are 66 ft. each. The pipe is 36 in. in diameter and is constructed of $\frac{1}{2}$-in. plates at the points of support and of $\frac{1}{4}$-in. plates at the center of the span. The fact that the wall thickness is less at the center of the span than at the points of support may seem strange at first glance, but it is justified by actual design considerations.

ton, Mont. Each of the two center spans is 126 ft. long, while the two end spans measure 98 ft. The thickness of the pipe at the points of support is $\frac{3}{4}$ in. and the wall thickness at the center of the span is $\frac{3}{8}$ in. In addition to the live load, this pipe was designed to withstand stresses due to earthquakes, as the installation is not many miles from the fault near Helena, Mont. A walkway and pipe railing are also provided on the top of this pipeline.

The longest span of ring girder construction in the world at the present

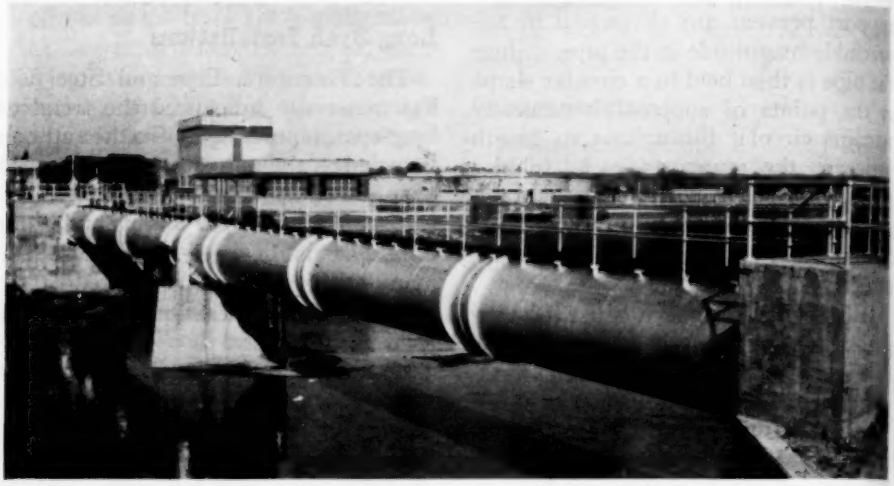

FIG. 1. Platte River Pipeline

Along the top of the pipe a walkway with a pipe railing is provided, over which a Wyoming cowpuncher is said to have ridden his horse. For convenience of erection, the pipe at Crowheart was provided with flanged joints at the points of contraflexure. There is no bending at these joints, the only stress being shear. This type of construction, however, is patented.

An 84-in. diameter pipeline has been built across the Missouri R. near Tos-

time is at Cody, Wyo. This pipe is 123 in. in diameter, with a center span 150 ft. long and two end spans of 8 ft. each. The wall thickness is $1\frac{5}{8}$ in. at the points of support, 1 in. at the center of the 150-ft. span and $\frac{7}{16}$ in. in the 80-ft. spans.

Technical Design

When particularly long spans are to be used in ring girder-supported pipe, good design and proper field erection

are equally important in building a safe, workable pipeline. If a good design is made but precaution is not taken in the field erection, the results are apt to be disastrous.

Because there is sufficient information available on the technical design of this type of pipe construction, this aspect of the subject will not be dealt with at length in the present paper. The most valuable contribution to the technical design of ring girder pipelines was presented by Herman Schorer (1) in 1933. His article, and the discussions of it, give all the formulas and derivations necessary to make the calculations for the design of stiffener ring-supported pipe. Another valuable source of technical information is a U.S. Bureau of Reclamation report (2) on the design of the Hoover Dam penstocks.

Several factors may be mentioned which have proved useful in the design of stiffener ring-supported pipes. The maximum allowable stress in the ring girder for pipe fully loaded is 10,000 psi. A maximum ring stress of 18,000 psi. may be allowed when the pipe is half full of water, which is the period of greatest stress for lines operating under a very low head. For the pipe shell a maximum stress of 10,000 psi. is allowed, to meet the worst loading conditions. Usually the stresses in the pipe when full and under pressure are the critical conditions to which the design stress of 10,000 psi. applies.

Ring-girder-supported pipe can be designed for single spans supported on each end; however, it is generally used for multiple spans to support the pipe above the ground, in tunnels or in rocky terrain where excavation is expensive, as well as to keep the pipe out of bad soils or to cross streams and other depressions.

FIG. 2. Crowheart Long-Span Pipe

On particularly long spans, it may be wise to allow for vertical camber in the spans so that when the pipe is fully loaded the bottom of the pipe will be in a straight line.

In making calculations of stresses in stiffener ring-supported pipe, the fol-

lowing procedure is used: After the span lengths have been determined, bending moment and shear diagrams are drawn, from which the reactions of the points of support are found. The next step is to assume a particular type of stiffener ring and to calculate its section modulus and cross-section area. Then the calculations for the pipe shell are worked out. The formulas for all of these operations except the bending-moment and shear diagrams will be found in Schorer's paper (1). Multiple-span installations should be designed as continuous beams. The negative and positive bending moments of the structure designed as a continuous beam will balance best if the two end spans are approximately eight-tenths of the length of the center or the intermediate spans. Three moment equations for the solution of moments in continuous beams and for shear diagrams appear in any good handbook.

In calculating the pipe wall thickness, it will be found that, on account of the high stresses at the points of support, the wall at those points and adjacent to them will be much heavier than the wall at the center of the span. The high stresses at the points of support are a combination of the negative bending moment and the stresses which occur in the pipe shell because the restraining action of the ring girder prevents the pipe from expanding under internal pressure.

Ring Girder Sections

Figures 3–6 show the general types of ring girder sections used in actual designs. A single ring welded to the outside of the pipe is illustrated in Fig. 3. This type of support is used only on small pipe or on medium-size pipe in which the span is comparatively short.

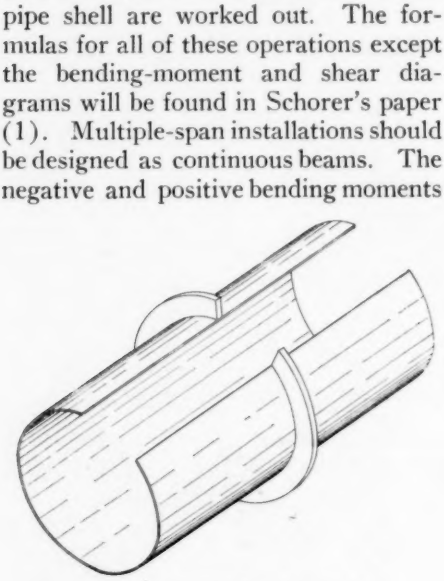

FIG. 3. Single-Ring Support

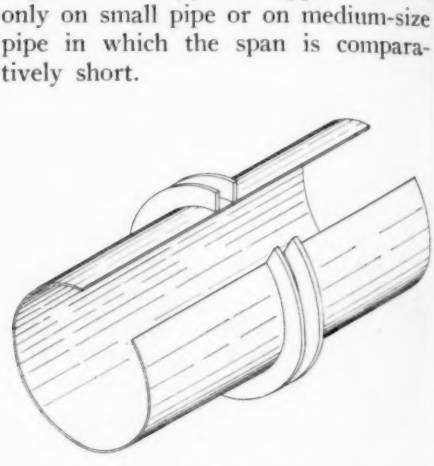

FIG. 4. Double-Ring Support

In Fig. 4 double simple rings are shown, which can be employed on rather large pipes and on comparatively long spans. The spacing between rings is usually equal to the ring width. The two rings must be tied together with plate diaphragms in the space between the rings and at right angles to them at sufficient intervals, to prevent the rings from tipping over.

Both single- and double-ring supports can be curved from steel bars bent edgewise, or they can be made by flame-cutting curved segments out of plates and then welding these seg-

ments to each other and to the pipe shell.

Figure 5 shows a **T**-section ring. This type may be curved from a standard structural **T**, or it can be built up by curving a flat steel bar to fit around the outside of the pipe shell and either curving or flame-cutting a flat bar or steel plate to form the stem of the **T**. Whichever way it is made, it is then welded to the outside of the pipe. The **T**-section ring can be used on fairly large pipe and also on relatively long spans. A triangular steel gusset plate should usually be welded at sufficient intervals on each side of the stem of the **T** to prevent overturning.

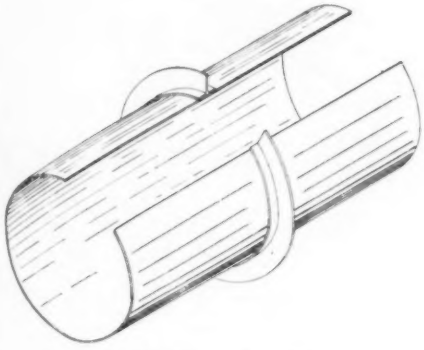

FIG. 5. **T**-Section Ring

When a large section modulus is required, a ring girder of **H** cross section, as shown in Fig. 6, should be used. This type of ring may be made by curving two structural **T**'s, one with the stem out and the other with the stem in, and then welding the points of the stems together to form the **H**. The **H**-section, however, is usually made up of segments which are flame-cut from plates and from flat bars. The **H**-section ring girder has the advantage that the width of the part which attaches to the pipe shell can be made quite large, if necessary, in order to reduce the stress in the pipe shell at the point of support. Steel-plate diaphragms should be used in this type of ring girder to prevent buckling of the web of the **H**.

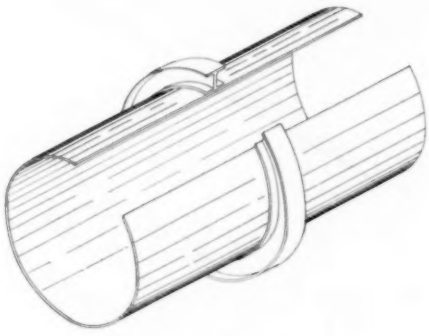

FIG. 6. **H**-Section Ring

Types of Supports

With any one of the four types of rings described, each of the four types of supports shown in Fig. 7–10 can be used. The connection between the supporting base and the ring will, of course, have to be shaped to fit the type of ring to which it is to connect.

Figure 7 shows the simplest type of support, used on small-diameter pipe and comparatively short spans. It consists of steel bars and a steel-plate section welded to a simple ring. The steel plate shown underneath the pipe usually replaces the section of the ring which would normally go in that position. The kind of support shown in Fig. 8 is to be used where the pipe will move longitudinally because of temperature changes. It will be noted that slots for movement are provided in the base plate. The lower plate is, of course, a bed plate which is not slotted but has holes to fit over the

anchor bolts. The slotted hole should be made large enough so that a short pipe thimble, if placed around the bolt and in the slot, will prevent the washer from being tight against the slotted plate when the nut is tightened. This support, with legs sufficiently heavy and of the correct shape to fit the ring girder involved, is used at the fixed ends of all types of pipe. When employed for this purpose, the holes are not slotted and the nuts or washers, of course, fit tightly against the top of the plate.

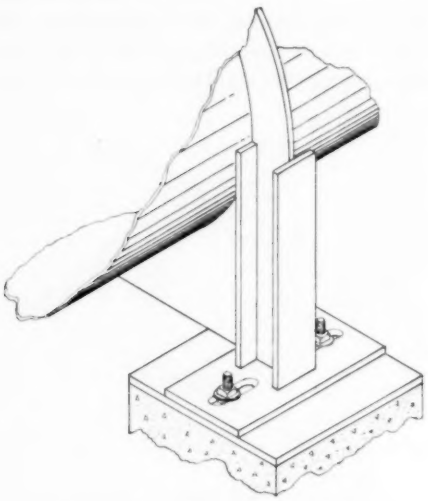

FIG. 7. Simplest Type of Support

For comparatively large pipe with medium-length spans, a type of support similar to that shown in Fig. 7 has been used successfully. Graphite-inserted flat bronze bearing plates are placed between the base plate and the moving plate on the bottom of the support leg.

Figure 8 shows a patented roller support which is designed to allow movement back and forth during temperature changes and, at the same time, to restrain the pipe from being lifted by flood or wind. Such a support can be used on even the largest diameters of pipe on the longest of spans. A supporting leg extends down from the ring girder and overlaps a base fitting which is attached to the concrete. Both of these members have oblong holes into which are inserted bronze bushing blocks. A pin through these blocks and through the steel roller shown in the sketch ties the whole unit together. Grooves in the roller and projections on the base plate and the leg member keep the assembly from moving sidewise.

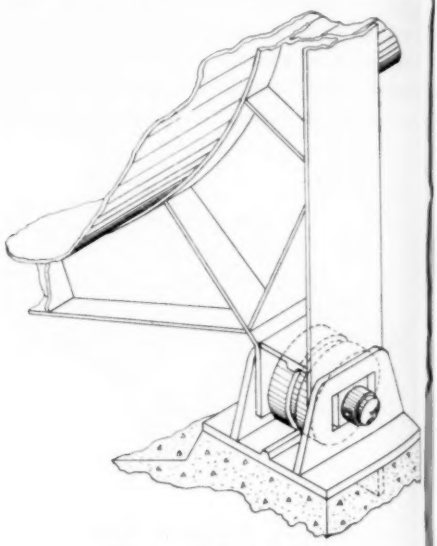

FIG. 8. Roller Support

The supporting assembly shown in Fig. 9 is similar in plan to that of Fig. 8 but a rocker has been substituted for the full round roller. This permits longitudinal movement of the pipe and prevents uplift and sidewise motion. The bronze block of Fig. 8 has been eliminated, and the pins are merely inserted in slotted holes in the plates of the overlapping parts of the leg and base plate. This results in a

simplification and is generally used on pipe of medium diameters for comparatively long spans.

Figure 10, which illustrates a general arrangement of pin-end bents for connections between the ring girder and the foundation, is self-explanatory. Short or tall bents can be used, depending upon the field conditions. If the pipe is particularly long, so that there will be considerable longitudinal movement because of temperature changes, short bents obviously cannot be used, as the angular movement of the bent will cause the bottom of the pipe to rise and fall, adding secondary stresses to the pipe shell.

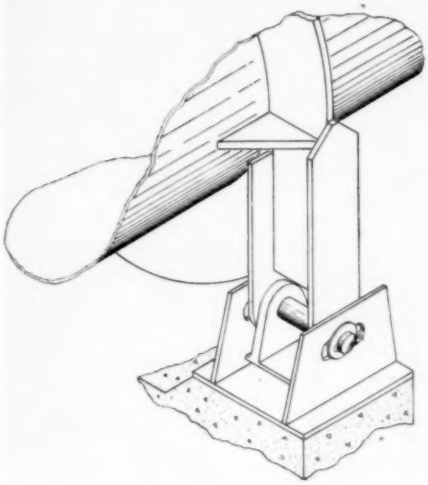

FIG. 9. Rocker Support

Field Erection

There are three principal requirements for the successful field erection of long spans of steel pipe: (1) the centerline of the lengths of pipe must be in perfectly straight alignment when they are tacked together for welding; (2) the rays of the sun must be prevented from throwing a bow or bend in the pipeline because one side becomes warmer than the other; and (3) correct welding procedures and competent welding operators must be employed in welding the pipe together, so that a welded joint will be obtained which is equally as strong as the steel of the pipe itself.

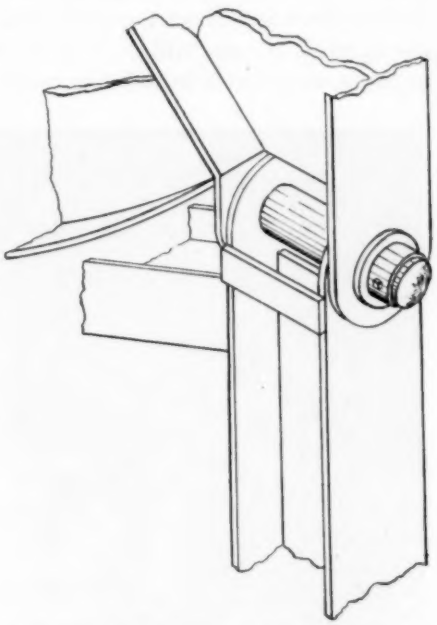

FIG. 10. Arrangement of Pin-End Bents

Alignment

In order to be sure that the pipe is in perfect alignment and to take care of the camber, if used, it will usually be necessary to erect the pipe on some kind of false work. A timber structure consisting of four legs and a working platform at each field joint may be sufficient. If the pipe is to be erected over a flowing stream, however, it may be necessary to drive some piles. Whatever type of false work is used, it must afford good working conditions for the fitter and the welder, and must hold the pipe to grade and line.

Prevention of Movement

Preventing the pipe from movement due to the action of the sun's rays may present quite a problem. It is sometimes necessary to throw a canvas over the pipe so that the direct rays of the sun will not heat one side and lengthen it. Even though a canvas is used, it may still be necessary to pump water on it in order to maintain an equal temperature all around the circumference of the pipe. It does not take very much of a temperature difference on one side of the pipe to cause considerable trouble. To prevent distortion, it is obvious that the actual centerline of the pipe after it is completed must coincide with the theoretical centerline as closely as possible.

In addition to keeping the pipe straight at each span, it is also necessary to restrain it from movement at each point of support during erection, a fact which is well illustrated by an experience with the effect of the sun's rays on a 52-in. pipe several years ago. During cloudy weather the field crew had erected 350 ft. of pipe, which was anchored at each concrete supporting pier with wood blocks. The base plates and rollers, of course, could not be installed until the pipe was completely erected. One afternoon the sun came out and heated one side of the pipe. Within a very short time the pipe began to bow until it kicked out the wood blocks which were restraining it laterally. Soon the two ends of the pipe were 42 in. out of line with the center of the 350-ft. run. At night, when the pipe went back into a straight line, the field crew temporarily welded the stiffener rings to reinforcing bars in the concrete so that lateral movement was prevented.

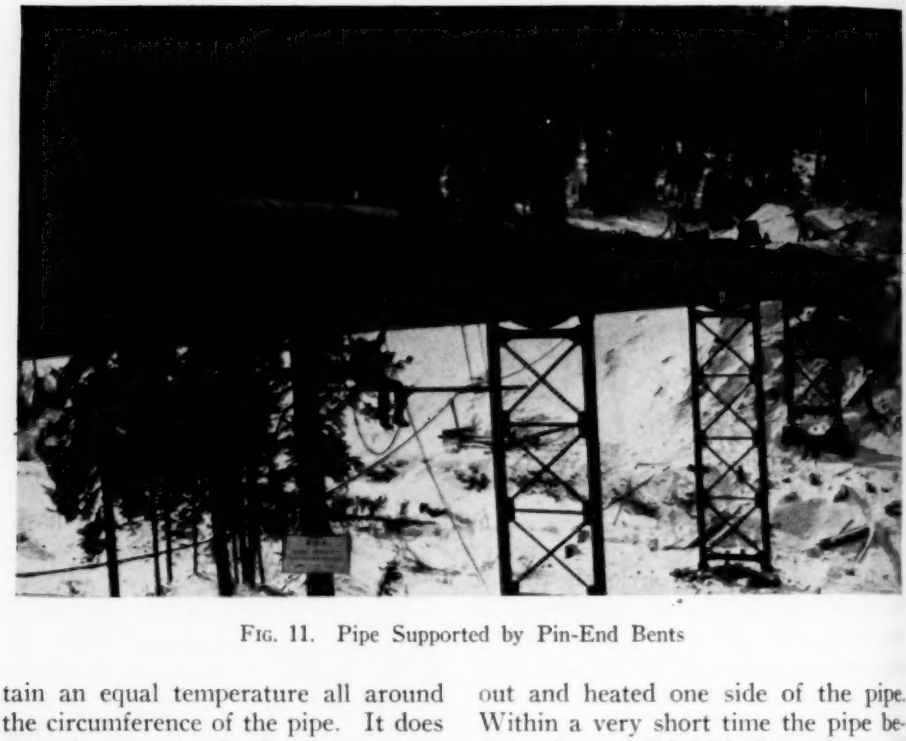

FIG. 11. Pipe Supported by Pin-End Bents

Welding Procedure

No one but a thoroughly competent welding operator should be allowed to weld the field joints. When a pipe is large enough for the welding operator to get inside, it should be welded inside and outside. The ends of the pipe sections should be single- or double-beveled, depending on the thickness of the material from which it is fabricated. The A.W.W.A.-A.W.S. Tentative Standard Specifications for Field Welding of Steel Water Pipe Joints (3) are satisfactory, provided the specifications are modified so that full penetration is obtained and the strength of the weld is equal to the strength of the parent metal.

Figure 11 shows an operator, working from a hanging scaffold, welding a seam of 72-in. diameter pipe. The pipe was assembled on timber bents consisting of two poles with a sill across the top for support. After the pipe joints had been tack-welded, the timber supports were removed and the welding was completed from a hanging scaffold. At the time the picture was taken the temperature was − 30°. The installation shown is part of the collection system of the Moffat Water Tunnel Diversion of the Denver Board of Water Commissioners. The pipe is supported on pin-end structural steel bents. The installation was made in the mountains west of Denver at an elevation of 10,000 ft. above sea level.

Because the work was done in the winter, particular care had to be exercised in the selection of a welding procedure which would be successful at temperatures considerably below zero. Despite the very low (0.12 per cent) carbon steel used in the manufacture of the pipe, its tensile strength was around 50,000 psi. The thickness of the steel was $\frac{7}{16}$ in. at the field joints. The welding was done in six passes. Before starting to weld, the operator heated the pipe with an oxy-acetylene torch a few feet on each side of the welding area. From then on, the procedure was to back-step the welding and heat the pipe at regular intervals with the torch. A $\frac{3}{16}$-in. Type V 6010 rod was used.

It has proved impractical to set the base plates—on which the support legs and their fittings rest—before the pipe is erected. Temporary wood blocks placed on the concrete piers for the stiffener rings to rest on will support the dead weight of the pipe. Lateral movement is taken care of, as already mentioned, by welding steel links from the stiffener ring to reinforcing bars in the concrete. After the pipe has been erected and the field joints welded, the base plates and the rollers or other fittings are lined up under the supporting legs. When all parts

FIG. 12. Undamaged Debris-covered Pipe

are carefully aligned, the base plates should be welded to the anchor bolts or some reinforcing bars; then the pockets under the base plates are filled with grout. If the base plates are not fixed solidly to the pier while the grout is setting, the longitudinal movement of the pipe due to temperature changes will cause the base plate to move back and forth in the green grout.

Protective Coatings

It has been the usual practice either to paint the pipe inside with coal-tar paint or to line it with coal-tar enamel according to A.W.W.A. specifications (4), depending upon the corrosive condition of the water and whether the pipe is to be empty or full during periods of below-zero temperatures. The outside of the pipe is usually primed in the shop with one coat of red-lead or zinc chromate paint; after erection another coat of red-lead or zinc chromate paint is applied, followed by two coats of aluminum paint, all of which are sprayed on. In the mountains west of Denver aluminum paint which has been in service nine or ten years is still in good condition. Besides affording protection to the pipe surface, the aluminum paint reflects the sun's rays and keeps the pipe much cooler while it is empty.

Durability of Steel Pipe

Although stiffener-ring long-span steel pipe has been installed with very thin walls and has been subjected to conditions more severe than those contemplated when the design and installation were made, the pipe has given excellent results.

A 96-in. diameter steel pipeline, having 55-ft. spans only $\frac{1}{4}$ in. thick at the center, was laid across a canyon with the bottom of the pipe 6–8 ft. above the stream bed. Several years after the installation was made, a cloudburst occurred in the watershed above the line. The ensuing flood brought trees and rocks from the sides of the mountain and piled them against the pipe, as shown in Fig. 12. Some rocks half the size of an office desk were thrown completely over the top of the pipe. In spite of this severe abuse, the line was undamaged. The thin steel pipe itself was not even dented. Steel has the great strength and durability needed to absorb such shocks as were caused by the flash flood. After the flood it was decided not to remove the debris, and the pipe is still operating in this condition.

It is hoped that the information presented on ring girder construction will be of help in using this economical means of designing long-span steel water pipelines.

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Chemical Properties of Chlorine Dioxide in Water Treatment

By R. S. Ingols and G. M. Ridenour

A contribution to the Journal by R. S. Ingols, Research Assoc. Prof., Georgia Institute of Technology, Atlanta, Ga., and G. M. Ridenour, Assoc. Prof. of Public Health Eng., School of Public Health, Univ. of Michigan, Ann Arbor, Mich.

PREVIOUS field studies (1–5) and laboratory data (6–8) have indicated some of the results that may be expected from the use of chlorine dioxide in water treatment. Not much information is available, however, on the chemical reaction characteristics of the gas. The authors have had the opportunity to observe some of these characteristics in the course of various laboratory investigations on the use of the material for water treatment. It is thought that the data presented in this paper may provide an approach to a better understanding of some of the properties of chlorine dioxide in its application to water treatment processes.

Some of the items of interest investigated were: (1) the preparation of chlorine dioxide for laboratory studies; (2) its stability in water solutions; (3) methods of measurement of chlorine dioxide in stock solutions and in the presence of reacting materials; (4) measurement of chlorine dioxide demand; (5) the oxidation capacity of chlorine dioxide for various typical organic materials in dilute concentrations; and (6) the reaction characteristics of chlorine dioxide in natural waters representing various degrees of domestic organic pollution. In the latter portion of the paper this information has been integrated to describe the fundamental mechanism of the behavior of chlorine dioxide in water.

General Survey

The preparation of chlorine dioxide in water treatment plant practice has been discussed by Synan, MacMahon and Vincent (4), and is described in further detail by Vincent (9). In brief, the method consists of mixing a solution of chlorine with a solution of sodium chlorite and adding the mixture directly to the water supply. In actual practice, a solution of sodium chlorite is pumped from a solution tank with a hypochlorinator into the discharge line from a regular chlorine feed machine. The reaction can be represented by the equation:

$$Cl_2 + 2NaClO_2 \rightarrow 2ClO_2 + 2NaCl$$

The necessary conditions for economical generation were also described by Vincent (9). This method for plant-scale generation is desirable since it utilizes existing chlorination equipment

in the filtration plant. Furthermore, it avoids the necessity for handling chlorine dioxide as a dry gas mixed with air, a mixture which is extremely unstable and which may react explosively if the concentration of chlorine dioxide is excessive. If the partial pressure of chlorine dioxide does not exceed about 50 mm., no hazardous condition is considered to exist. A summary of the general properties and some of the precautions to be used in handling the material are given in two articles by Taylor *et al.* (10, 11), which also include many of the general theoretical reactions as well as a review of the literature on chlorine dioxide.

Laboratory Preparation

The method of preparing chlorine dioxide used in plant practice is not desirable for laboratory study, because it leaves an equivalent amount of sodium chloride in the final solution. And all of the chlorine and sodium chlorite does not react in equivalent amounts when mixed (9). An excess of chlorine over the stoichiometrical amount is used to avoid such inefficiencies. The chloride ion might not only interfere in a theoretical interpretation of the results, but could also hasten the rate of decomposition of the chlorine dioxide in the stock solution (6), thus reducing its stability. A pure solution of chlorine dioxide for the laboratory can be secured by slowly adding a 10 per cent solution of sulfuric acid dropwise to a 10 per cent solution of sodium chlorite. The liberated gas is scrubbed out of the solution into a small volume of double- or triple-distilled water by a slow stream of air induced with an aspirator. A solution of 7,000 ppm. ClO_2 (expressed as Cl_2) can readily be generated in this manner. The reaction involved in this method of making chlorine dioxide is apparently:

$$5NaClO_2 + 2H_2SO_4 \rightarrow 2Na_2SO_4 + 2H_2O + 4ClO_2 + NaCl$$

This reaction has been partially confirmed by determining the quantity of chlorides produced from a known amount of sodium chlorite.

Stability in Water Solution

From a review of the literature, Mellor (6) comes to the conclusion that "chlorine dioxide is not hydrolyzed in aqueous solution." This statement is based on evidence obtained from the relative solubility of the gas in water and carbon tetrachloride. Mellor's conclusion was checked by making a fresh strong solution of chlorine dioxide. It was shown by acid iodide titration that the solution was 37.5 millimolar while the pH was 4.75, and 100 ml. of solution required 0.35 ml. of $\frac{1}{10}$ *N* NaOH to give a pH of 8.7, or only 0.35 milliequivalents of acid per 37.5 millimoles of chlorine dioxide. This indicated that not more than 1 per cent of titratable acid was present, possibly as a product in the partial breakdown of the chlorine dioxide.

Laboratory studies show, however, that both pH and temperature are important factors in the stability of the gas in water solutions. In conducting potentiometric titrations at room temperatures, it has been noticed that there is a rather rapid and steady drift downward from an elevated pH value. For instance, in one experiment a pH value of 8.7 was the highest reading obtained; after 45 minutes the pH dropped to 3.4. In another experi-

ment it went as low as 2.4. It has been found that from pH 6.5 upward the chlorine dioxide tends to break down even in the absence of a reductant, although it has frequently remained stable for at least 24 hours at pH 8.0, as shown by results given later in this paper. The freshness of a chlorine dioxide solution can be tested by a comparison of the pH values at the beginning and end of the storage period to indicate the degree of breakdown. The effect of temperature on stability is of equal importance to that of pH. For example, a sample was stored in the refrigerator for two days without any change in pH or oxidation capacity, but at room temperature only five hours' time was needed to initiate a marked change in pH. Consequently, temperature and pH are very significant factors in the stability of the gas.

Chlorine Dioxide Measurement

The concentration of chlorine dioxide in stock solutions can be determined by methods similar to those used for chlorine solutions (12), except that some special precautions must be taken and the values must be properly interpreted. Chlorine dioxide is a compound containing oxygen, so that its oxidation capacity is dependent upon pH to a greater extent than is that of chlorine. For example, an alcoholic solution of potassium iodide, when added to an aliquot *pure solution* of chlorine dioxide, buffered to pH 7.8 with 200 ppm. of sodium bicarbonate, will liberate one-fifth as much iodine (measured by sodium thiosulfate and starch indicator) as when concentrated hydrochloric acid is added to a similar aliquot of the chlorine dioxide solution and the iodine titration repeated. This difference can be explained from the literature by the reaction of the chlorine dioxide with potassium iodide at pH 7.8:

$$ClO_2 + I^- \rightarrow (ClO_2)^- + I^0$$

or:

$$ClO_2 + e \rightleftharpoons (ClO_2)^- \quad [E_0 = -1.15\text{v.}]$$

In this reaction a chlorite ion is formed from chlorine dioxide by the uptake of one of the five possible electron changes of the chlorine dioxide. However, the complete breakdown of all five electron changes of the chlorine dioxide requires the presence of the hydrogen ion:

$$ClO_2 + 5I^- + 5H^+ \rightarrow HCl + 2H_2O + 5I^0$$

This relationship shows the importance of maintaining proper conditions when measuring chlorine dioxide. Laboratory studies made by the authors indicate that 1.5 is the highest pH which will allow the development of the full oxidation capacity of chlorine dioxide to iodide. One milliliter of concentrated hydrochloric acid in a 25-ml. sample of the chlorine dioxide solution containing 200 ppm. alkalinity and 5 ml. alcoholic potassium iodide (12) will give a pH of 0.8. This allows a reasonable margin of safety if the sample has some extra alkalinity. Glacial acetic acid, as sometimes proposed for chlorine (1 ml. in a 25-ml. sample), will not produce a pH low enough to develop the complete oxidation capacity of chlorine dioxide.

It has been established that chlorine dioxide plus hypochlorites rearrange to form hydrochloric and chloric acids or their salts (6, 10, 11). From its formula, it would seem possible that chloric acid might also be included in

the analysis of a partially reacted mixture of chlorine dioxide and chlorine, if the chlorate ion is decomposed at the same pH needed for the determination of chlorine dioxide. Tests run on sodium chlorate solution showed, however, that no iodine was liberated from iodide until the hydrogen ion concentration exceeded molarity. Almost 10 ml. of concentrated hydrochloric acid to 25 ml. of sodium chlorate solution was required to give total recovery of the oxidation capacity of the chlorine residuals in plant practice. Acid ortho-tolidine, though similarly subject to certain inaccuracies, is more widely used and is also somewhat better for eliminating interfering compounds. Consequently, this method for the determination of chlorine dioxide residuals was also investigated. It was found, however, that only a portion of the chlorine dioxide was recovered by the acid ortho-tolidine procedure. As an example, when several aliquots of a stock solution of chlorine

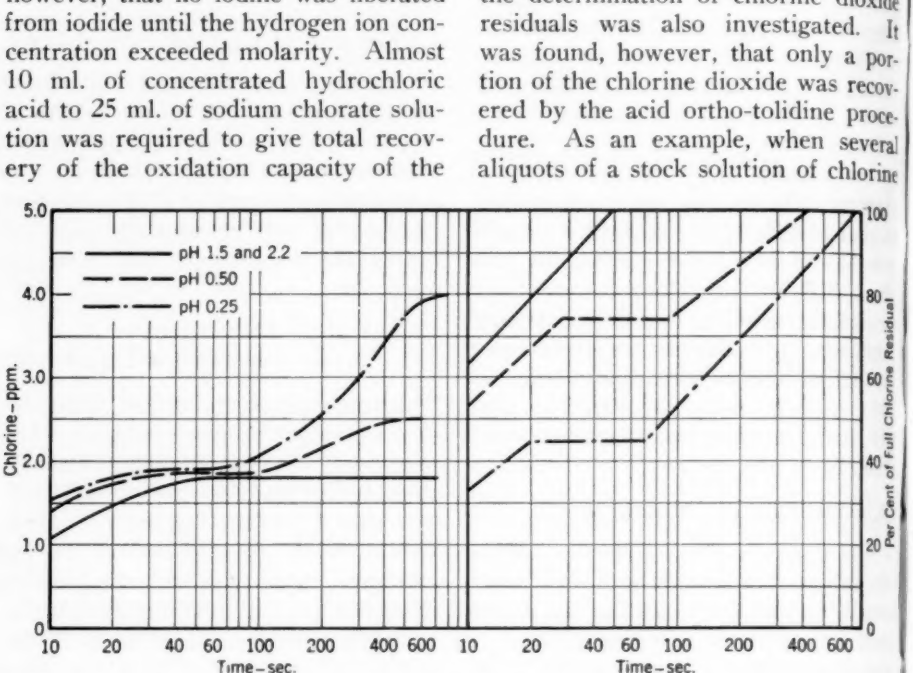

FIG. 1. Rate of Color Development (Ortho-tolidine and Chlorine Dioxide)

chlorate radical. This information indicates that the chlorine dioxide can be titrated to its maximum capacity by adding a ratio of 1 ml. of concentrated HCl to 25 ml. of the sample (0.5 *N*) without any chlorate interference.

The starch-iodide method for chlorine residual determination can be carried out with a high degree of precision but it is not always desirable, because the indicated value includes many chlorine compounds (13) and interfering substances. Moreover, it is not generally used for controlling

dioxide were taken, the following typical analyses were obtained:

Method of Analysis	pH	ppm.
Acid ortho-tolidine comparison (1:100 dilution)	1.9	100.
Neutral starch iodide	8.0	113.
Acid starch iodide	0.8	520.

These data indicate that the acid ortho-tolidine method gives approximately the same value as the neutral iodide titration method for chlorine dioxide and at pH 1.9 measures approximately one-fifth of the full oxidation capacity

of the chlorine dioxide. Results shown in Fig. 1 indicate that higher acid ortho-tolidine does increase the chlorine dioxide residual reading but, within the limits shown, does not develop a color value which corresponds to the full five-fifths of the oxidation capacity of chlorine dioxide. The lowest pH value shown requires the addition of a large excess of concentrated hydrochloric acid and is out of the range of a routine method; lower pH values therefore were not studied. Higher pH values, as with chlorine (12), fail to give a color which will match the standards. Consequently, it is apparent that the routine ortho-tolidine technique using pH values between 2.2 and 1.4 is satisfactory for studying the residuals of chlorine dioxide, but under these conditions the method measures only one-fifth of the total oxidation capacity of the chlorine dioxide. It should be noted that at the two lower pH values the development of the ortho-tolidine is a two-step reaction. It is considered likely that the second increase is due to the formation of more chlorine dioxide because of the hydrogen ion concentration, as shown under laboratory preparation. These data also show that, at the maximum, only 84 per cent of the full color will develop.

Although in pure stock solutions the standard ortho-tolidine test measures approximately one-fifth of the total oxidation capacity of chlorine dioxide as related to acid potassium iodide, this same relationship does not exist in the measurement of residuals after the gas has reacted with reducing substances. The acid potassium iodide test evaluates the unreacted chlorine dioxide, chlorite ion and all other partial reduction products of chlorine dioxide with a potential above iodide. The standard ortho-tolidine test measures approximately one-fifth of the oxidation capacity of the unreacted chlorine dioxide plus other reaction products capable of oxidizing ortho-tolidine. It does not measure the chlorite ion. Consequently, the 1 : 5 ratio which holds very closely true in pure chlorine dioxide solutions will vary in the presence of reactive material, depending on the amount of chlorite ion and other reaction products present. The knowledge that standard ortho-tolidine measures one-fifth of the full oxidation capacity of chlorine dioxide is therefore of value only in dealing with pure solutions.

Measurement of ClO_2 Demand

For practical measurements of chlorine dioxide demand, either the acid potassium iodide or standard ortho-tolidine methods of obtaining chlorine dosages and residuals may be used. Proper interpretation of the results must, however, be made in terms of the meaning of these residuals.

As previously mentioned, acid potassium iodide, in the presence of reacted organic material, may give a mixture of unreacted chlorine dioxide, chlorite ion and other reaction products of chlorine dioxide; each of these substances may oxidize iodide under acid conditions. Therefore, if chlorine dioxide is added on an acid iodide basis and the residuals are measured by acid iodide, the demand includes all chlorine dioxide reduced below the redox potential of iodine.

When chlorine dioxide is added on a standard ortho-tolidine basis—which represents in the pure stock solution one-fifth of the full oxidation capacity, or approximately one-half by weight

of the gas—and the residuals are measured by the same means, the chlorine dioxide demand by weight (in terms of ClO_2) equals 1.9 times the amount of ortho-tolidine added as chlorine minus 1.9 times the ortho-tolidine residual recovered as chlorine, exclusive of partial reaction products which may not react with ortho-tolidine.

Chlorine dioxide demand measurements referred to later in this paper, when made with either acid iodide or ortho-tolidine, have been computed on the basis of these interpretations.

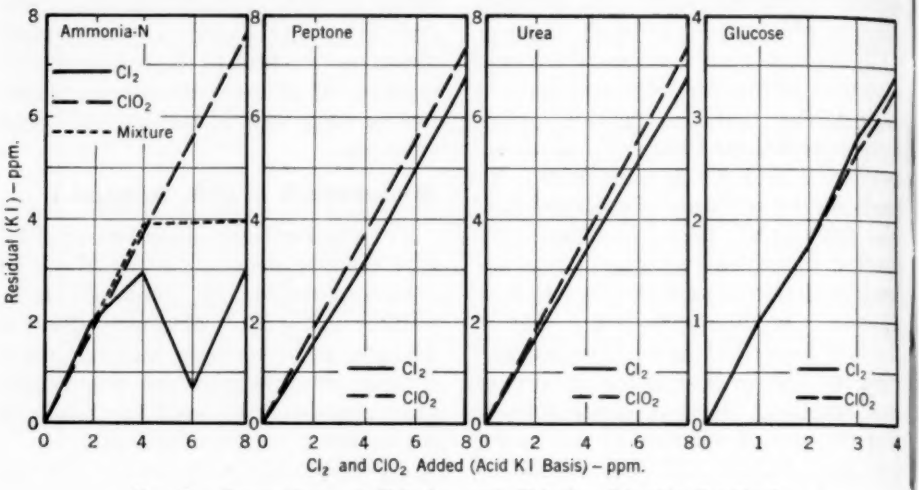

FIG. 2. Comparison of Chlorine and Chlorine Dioxide Residuals

Oxidation Capacity

The elimination of taste-forming substances by the use of chlorine compounds is generally associated with the oxidation capacity of the material. Theoretically, the oxidation capacity of chlorine dioxide, in terms of available chlorine, is $2\frac{1}{2}$ times that of chlorine (4, 11), assuming that all five electron changes are involved in oxidation. It has been shown, however, that chlorine dioxide does not break down to this extent in the oxidation of ortho-tolidine. Studies were carried out on some typical organic substances—such as ammonia, phenol, glucose, urea and peptone—in 0.5-ppm. concentrations to see how completely the chlorine dioxide is broken down. The tests were made by adding known amounts of chlorine dioxide solutions of calibrated concentration to each of the organic substrates in glass-stoppered bottles. As a basis for comparison, similar tests were made on the same materials with chlorine. Since, in practice, both chlorine and chlorine dioxide are simultaneously used in treatment, a 1:1 mixture of both of the gases was added to a third group of solutions of the same materials. The three series were set up at the same time and titrated at the end of one hour and 24 hours. Triple-distilled water, which was shown to be free of ammonia, was used for the solutions to eliminate possible confusion of the results by small amounts of ammonia present in ordinary distilled water.

The results of these studies, taken from a large number of tests, are shown in Fig. 2 and 3. The graphs indicate the amount of residual of each gas or mixture of gases after one hour's contact time with 0.5 ppm. of the various organic materials. The residuals of chlorine, chlorine dioxide and their mixtures are expressed as chlorine, measured by the use of the acid iodide titration as previously described. A comparison of the residuals with the quantity of chlorine and chlorine dioxide added thus gives the extent of chlorine or chlorine dioxide consumption by the organic matter in the substrate.

The results in Fig. 2, in which the water has been buffered to pH 8.0 with 200 ppm. of sodium bicarbonate, show that chlorine reacts with the ammonia in a typical break-point reaction, whereas chlorine dioxide in the amounts added fails to do so. An increase of the chlorine dioxide concentration to 100 ppm. also failed to show any reaction with the ammonia. The inertness of ammonia with chlorine dioxide agrees with the results published by Palin (14). The reaction of the mixture of chlorine and chlorine dioxide with ammonia is intermediate in value between the reaction of the separately added gases. Neither chlorine nor chlorine dioxide reacts appreciably with peptone, glucose or urea at the concentration studied. The gas mixture curve is not shown for peptone, urea and glucose because it lies between the curves for the separate gases.

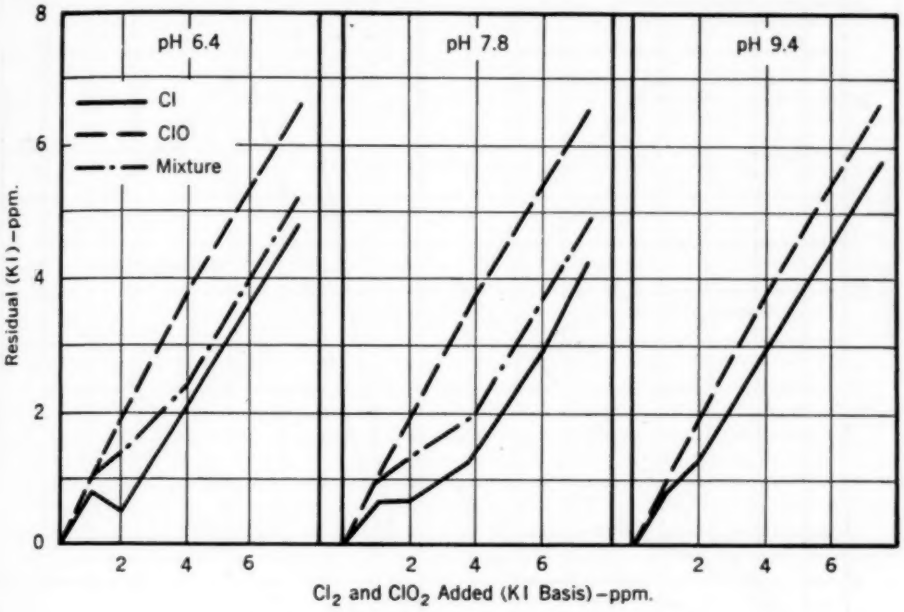

FIG. 3. Effect of pH on Phenol Demand

Figure 3 shows the residuals of chlorine and chlorine dioxide after one hour's contact with 0.5 ppm. of phenol

buffered to three different pH values. According to the acid iodide titration, chlorine reacts readily with the phenol at both of the lower pH values and to a limited extent at the higher value of 9.4. On the other hand, chlorine dioxide reacts with the phenol to a very limited extent and, at the concentration used, there is no change in reactivity over the entire pH range examined. At higher chloride dioxide concentrations, however, the authors have shown (15) that phenol will be oxidized to quinone or to maleic acid, depending upon the ratios present. The greatest reactivity of chlorine with phenol occurs at pH 7.8 because at higher pH values the chlorine has a lower redox potential, while at lower values the chlorine tends only to substitute (16) on the benzene ring rather than to oxidize the phenol as well. Substitution on the benzene ring requires less chlorine than oxidation of the phenol. The uniformity in the degree of reaction of chlorine dioxide

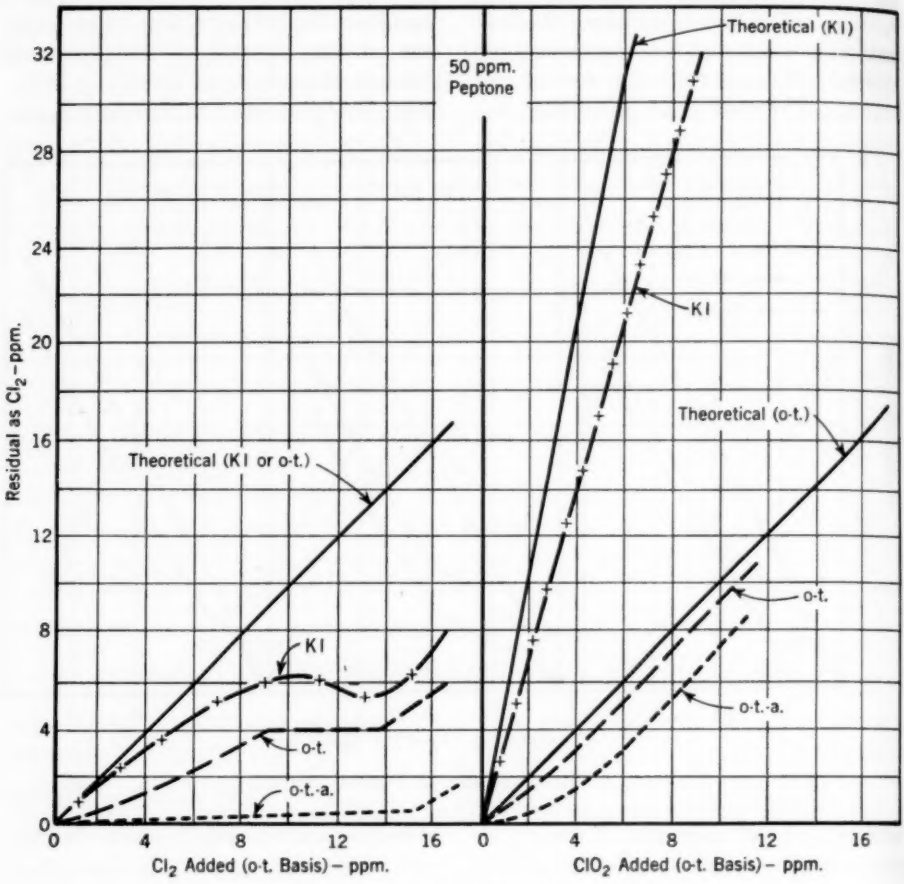

FIG. 4. Comparison of Tests for Chlorine and Chlorine Dioxide Residuals *

* The abbreviations "o-t." and "o-t.-a." shown in the figures stand for "ortho-tolidine" and "ortho-tolidine-arsenite," respectively.

with phenol at the different pH values, as indicated by acid iodide residuals, also holds true for a bactericidal study made by Hallinan (17) on polluted river water, even though his investigations were carried out with ortho-tolidine-arsenite residuals. At pH 6.4 and 7.8, the gas mixture curves were intermediate between those of the two gases separately, while at pH 9.4 the mixture curve was superimposed on the chlorine curve.

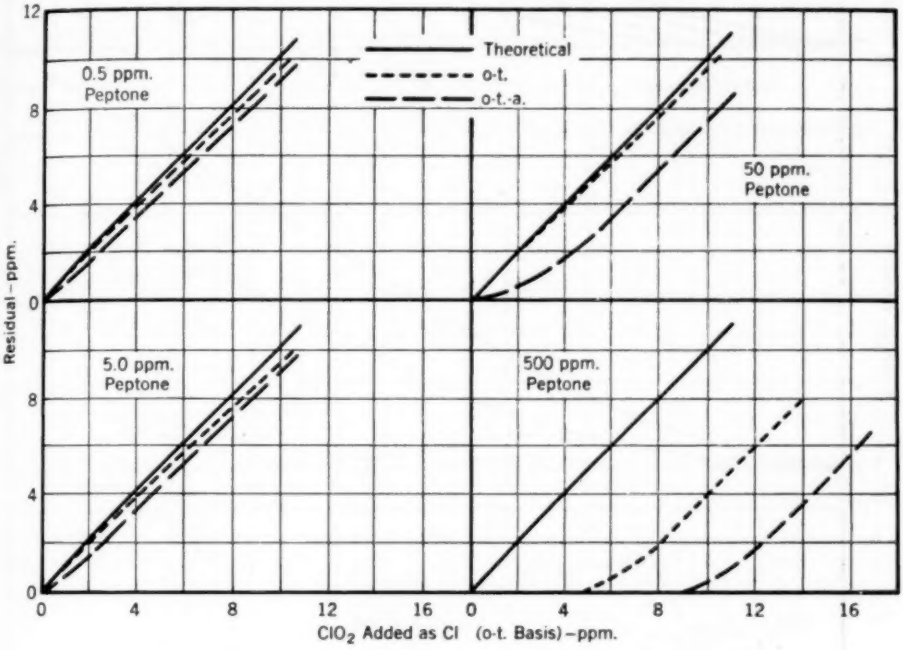

FIG. 5. Comparison of o–t. and o–t.–a. Chlorine Dioxide Residuals

The general lack of reactivity of chlorine dioxide with most of the compounds studied was at variance with the results of earlier work mentioned in the literature (4, 18). Two factors might be used to explain this difference: (1) very low concentrations of materials were used in this study to simulate conditions in natural waters; and (2) the use of acid potassium iodide may have indicated a nonreactive portion of the chlorine dioxide residuals which was not detected by the method employed in the previously published works. The parts which both of these factors play are surveyed in the experiments shown in Fig. 4 and 5. In Fig. 4 the residuals of chlorine and chlorine dioxide are plotted from three different methods of analysis after reaction with 50 ppm. of peptone for one hour. For each gas, the residuals indicated by acid potassium iodide are the highest and those by ortho-tolidine-arsenite are the lowest. By whichever method of residual determination the demand is compared, the chlorine dioxide shows the lower demand. The relative effects of various concentrations of organic matter on chlorine dioxide demand are shown in Fig. 5. The reactivity between the

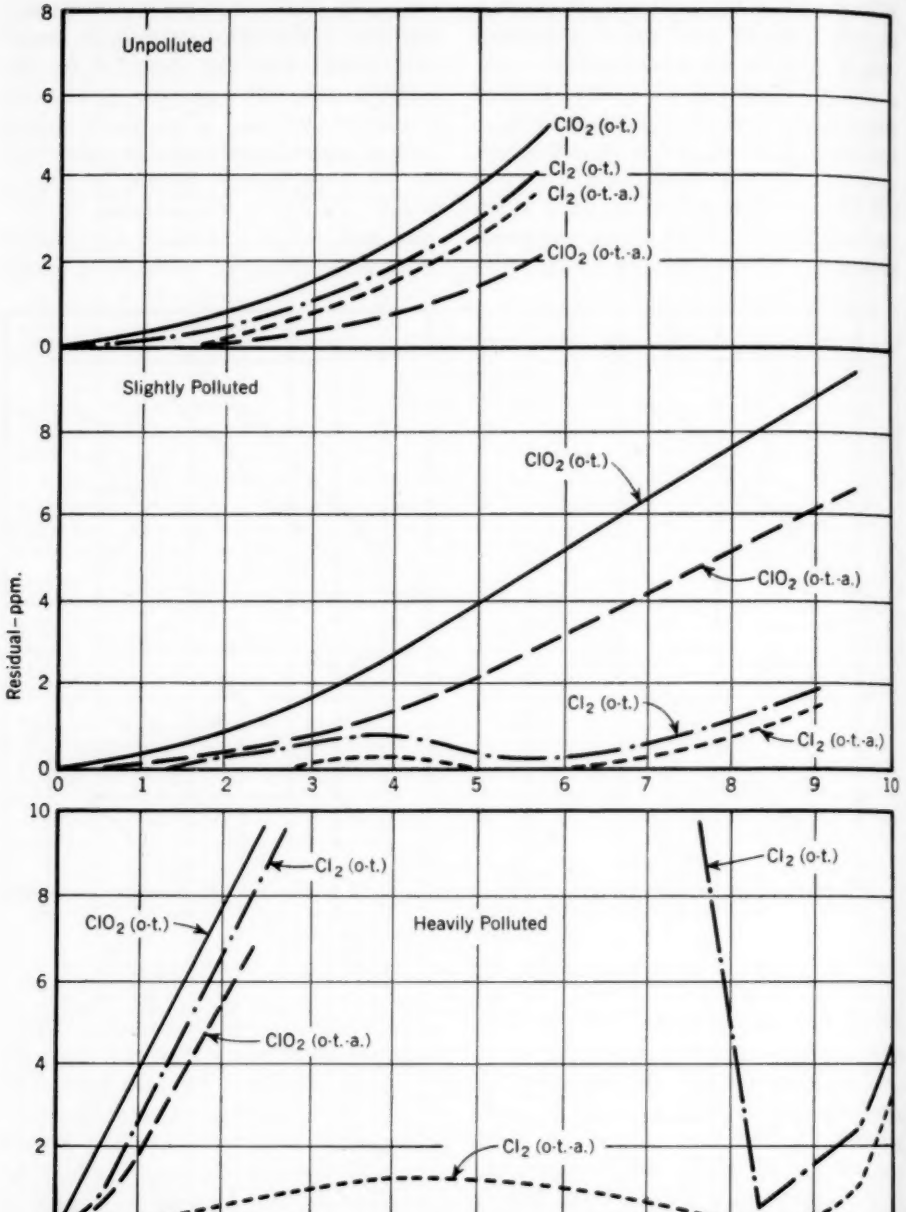

FIG. 6. Chlorine and Chlorine Dioxide Residuals in Natural Waters

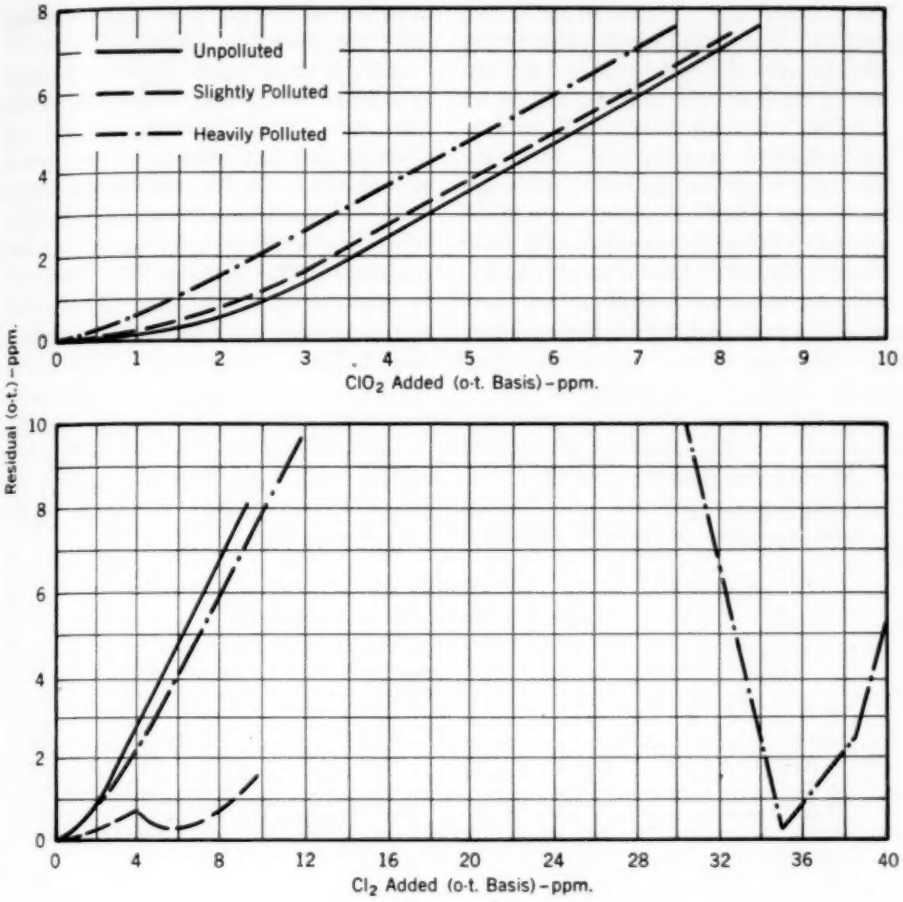

FIG. 7. Chlorine and Chlorine Dioxide (o-t.) Residuals in Natural Waters

peptone and chlorine dioxide increases as the concentration of the peptone increases; and the spread between the ortho-tolidine and ortho-tolidine-arsenite residual values becomes larger with increasing peptone concentration. These facts will be considered in detail later in this paper but are included here to indicate some of the general properties of chlorine dioxide.

In a study of phenol at higher concentrations than that used in Fig. 3, it was found that chlorine reacts more readily than chlorine dioxide with phenol according to every method of residual comparison employed.

Oxidation of Natural Waters

The foregoing studies were made on solutions of known chemical composition and were intended to show the reaction characteristics of chlorine dioxide with typical substances. The solutions simulate, but are not the same as, natural waters that contain many unknown materials of various kinds,

both soluble and insoluble, organic and inorganic. It is well known that rivers vary greatly depending upon the nature of their source and the degree of pollution. Studies were made on several different river waters from the area near Ann Arbor, Mich., to cover the range from a pure, unpolluted stream to a heavily contaminated river sampled directly below a sewer outfall. Eight samples were studied, but only three are reported, because they cover the extremes of the variations found in the study. The curves in Fig. 6 show the results (after 30 minutes' contact) of adding equivalent amounts of chlorine and chlorine dioxide to unpolluted, lightly polluted and heavily polluted stream samples. Chemical and bacteriological analyses of the waters are shown in Table 1.

In the unpolluted sample the orthotolidine-arsenite test shows a chlorine demand slightly lower than the chlorine dioxide demand. However, the orthotolidine test on the unpolluted sample and both tests on all the other samples analyzed indicate a chlorine demand as large as, or greater than, the corresponding chlorine dioxide demand. These results agree with the type-study results already reported. The curves in Fig. 7, which are a compilation of the ortho-tolidine test curves in Fig. 6, indicate the lack of variation in the chlorine dioxide residual values but show a tremendous variation in the chlorine residuals.

TABLE 1

Analyses of Natural Water Samples

Item	Unit	Unpolluted*	Polluted*	Polluted†
D.O.	ppm.	8.6	11.2	3.2
pH		8.2	9.0	7.6
NH_3–N	ppm.	0.3	0.4	4.3
NO_3–N	ppm.	0.2	0.1	0.4
Total bacteria	No. per ml.	50	380,000	70,000
Esch. coli	No. per ml.	1.3	120	500
Chloride	ppm.	9	12	46
B.O.D.	ppm.	1.6	4.4	3.3

* Huron R. sample.
† Grand R. sample.

Fundamental Concepts

Present indications are that chlorine dioxide is an un-ionized molecule dispersed in water, unlike chlorine, which combines with water to form hydrochloric and hypochlorous acids (6). However, tabulations show that the oxidation-reduction potential of chlorine dioxide is very close (within several hundredths of a volt) to that of chlorine. It has been reported (9) that chlorine plus sodium chlorite in equivalent amounts form an equilibrium mixture with chlorine dioxide and sodium chloride. In plant practice, therefore, it is recommended that an excess of the less expensive chlorine be used for the most economical handling of the more costly sodium chlorite in the production of chlorine dioxide. The fact that chlorine can be used to produce chlorine dioxide means that the compound must have a slightly lower energy level or greater stability than the element, or chlorine could not

bring about the formation of chlorine dioxide. Thus, it might be expected that the reaction rates of chlorine and chlorine dioxide would be similar, but that chlorine would react somewhat faster. The literature is confusing in this regard, because a greater ability to oxidize organic materials has been claimed by some writers (4, 18) for chlorine dioxide while the present authors have interpreted their data as indicating that chlorine dioxide is less reactive or slower in reaction rate than chlorine.

of ortho-tolidine at a pH above 1.9 but an increasing amount as the pH decreases. These facts indicate that chlorine dioxide breaks down in two stages: (1) the reduction from chlorine dioxide to chlorite ion; and (2) the reduction of the chlorite ion when there is enough hydrogen ion present and the reductant has a sufficiently low redox potential. The second step in the increasing oxidation of both iodide and ortho-tolidine at the lower pH values seems to be brought about by the formation of more chlorine di-

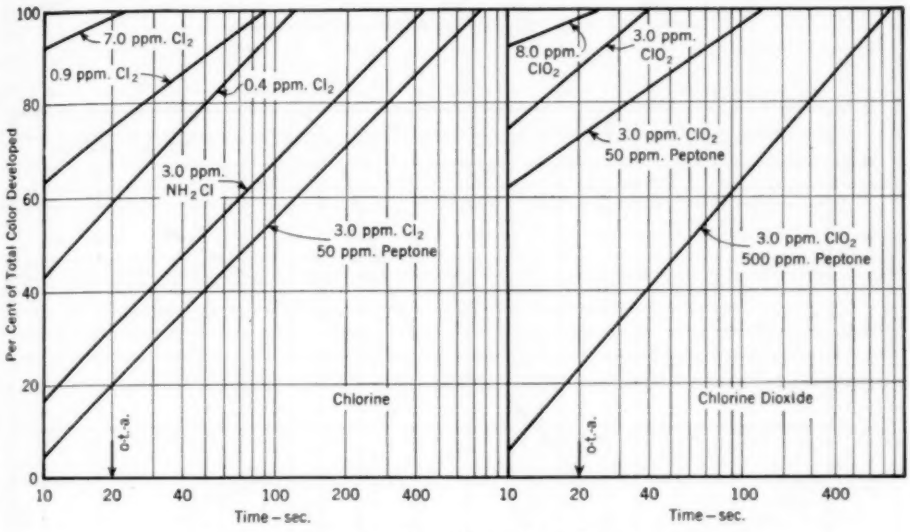

FIG. 8. Rate of Ortho-tolidine Color Development

Reaction With Ortho-tolidine

The problem of interpreting results when chlorine dioxide has been used is complicated by the fact that it shows two distinct oxidizing capacities against various substances. In the presence of sufficient acid and iodide, each mole of chlorine dioxide liberates 5 equivalents of iodine while in a neutral solution only 1 equivalent of iodine is liberated. Likewise, 1 mole of chlorine dioxide oxidizes only 1 equivalent

oxide from the acid and chlorite ion, as indicated by the reaction equation for the laboratory method of preparing chlorine dioxide. From a study of the reaction of the formation of chlorine dioxide from chlorine and sodium chlorite, it seems apparent that the rate of a chlorine dioxide reaction with some reductants will be comparable to the rate of reaction of the same reductant with chlorine only if the first stage of the breakdown of chlorine dioxide is considered.

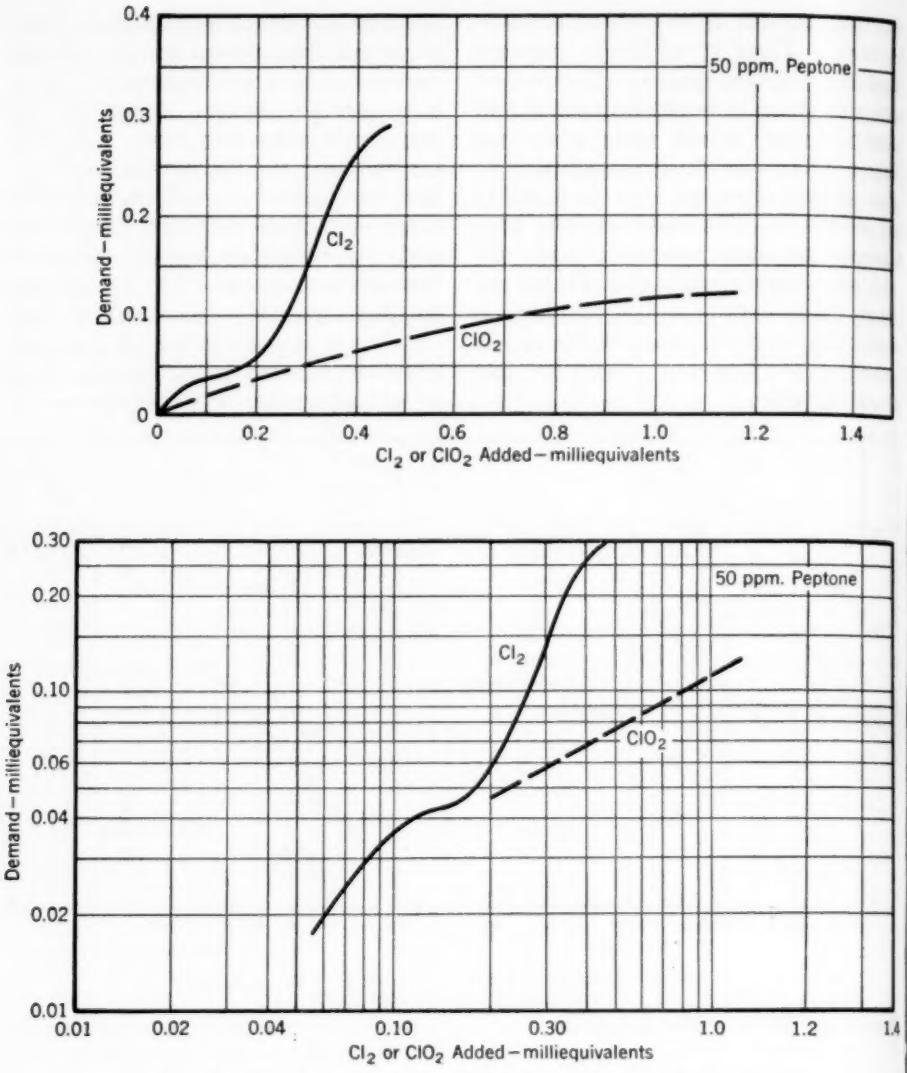

FIG. 9. Chlorine and Chlorine Dioxide Demand (Peptone)

Measurement by Ortho-tolidine

The data shown in Fig. 8 indicate that the rate of color development between either chlorine or chlorine dioxide and ortho-tolidine is a function of the concentration of these gases. The basic principle of the ortho-tolidine-arsenite test is that the rate of development of the ortho-tolidine color is a function of the redox potential. It is a further well-established principle that the redox potential is a function of concentration. The results in Fig. 8 are in conformity with these theoretical considerations. It should also be noted that the reading at the end of 20

seconds for each gas is a different percentage of the total color development. But the lowest concentration of either chlorine or chlorine dioxide, in the absence of reactive materials, gives a higher percentage of color development after 20 seconds than that given by the compounds of chlorine and the mixtures of chlorine dioxide with peptone, which have a higher total residual value. This indicates that the free chlorine dioxide solutions have higher redox potentials than their compounds or mixtures, just as is true for chlorine (19).

In the use of the ortho-tolidine-arsenite tests, therefore, not only the ortho-tolidine-arsenite value but also the ortho-tolidine value must be obtained in order to determine whether the solution contains free or combined chlorine dioxide, again as in the determination of chlorine.

Chlorine Dioxide Demand

In Fig. 9 the chlorine and chlorine dioxide demand is plotted for 50 ppm. of peptone. The upper part of the figure shows the curves on ordinary arithmetic graph paper while the lower portion uses log-log graph paper. From the log-log graphs it can be seen that the chlorine dioxide demand follows the laws of adsorption, as shown by the straight line with a slope of exactly 0.5. The slope of the chlorine

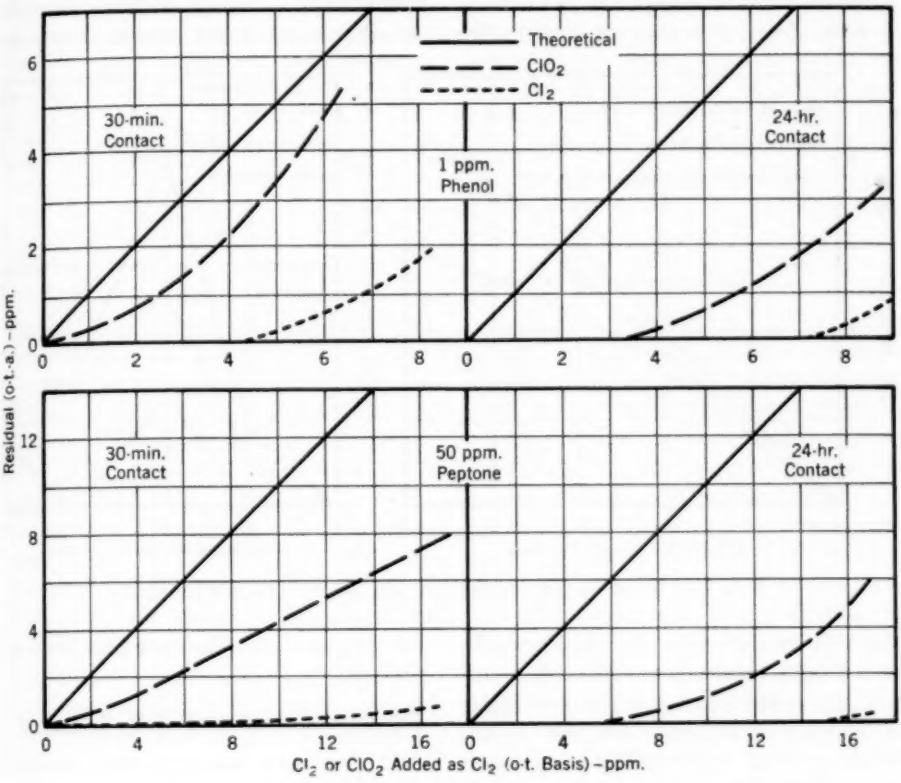

FIG. 10. Effect of Contact Time on Chlorine and Chlorine Dioxide Demand

demand curve is greater than 0.5, indicating that there must be a chemical reaction between the chlorine and peptone. These data imply that the amount of chlorine dioxide which will react with peptone is determined, at least in part, by the amount of chlorine dioxide entering the water layer of the peptone. This evidence that adsorption plays a large part in chlorine dioxide demand is also consistent with the results shown in Fig. 8, in which, at a 3-ppm. total chlorine dioxide residual, the ortho-tolidine-arsenite value is a smaller percentage of the ortho-tolidine value with 500 ppm. peptone than with 50 ppm. peptone. Evidently the 500 ppm. peptone has a larger amount of chlorine dioxide in its bound water layer than the 50 ppm. peptone, and the longer time of color development is due to the process of desorption. The ortho-tolidine-arsenite value of the chlorine dioxide would therefore be a true measure of the amount of free gas in solution, while the ortho-tolidine value would measure the free plus the physically bound molecules.

The data in Fig. 10 show the ortho-tolidine-arsenite residuals of both chlorine and chlorine dioxide at the end of 30 minutes' and 24 hours' contact with 50 ppm. peptone and 1.0 ppm. phenol. The longer contact period in no way alters the conclusion that chlorine is more reactive than chlorine dioxide, whether against the comparatively inert peptone or the readily reactive phenol.

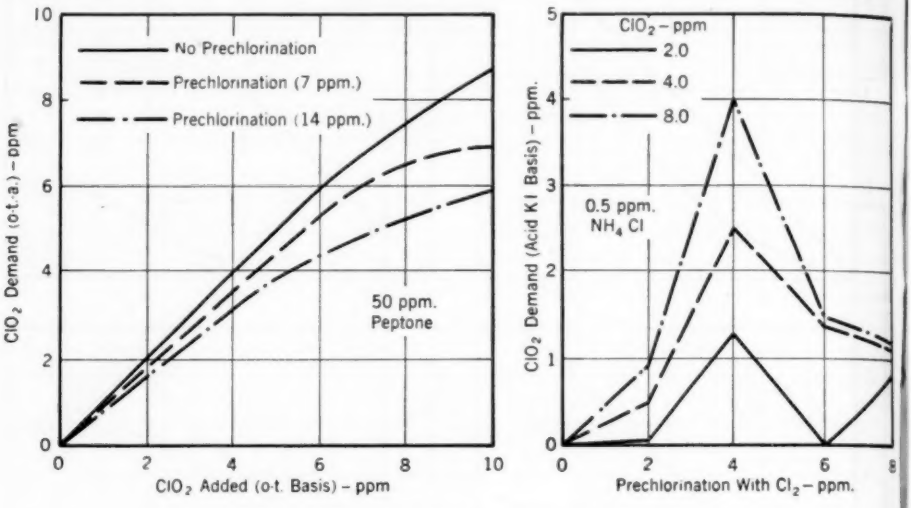

FIG. 11. Effect of Prechlorination on Chlorine Dioxide Demand

Prechlorination and ClO_2 Demand

It has been assumed that chlorine dioxide does the job of completing the oxidation of many chlorinated organic compounds in reducing the taste and odor of a chlorinated water. This might mean a higher chlorine dioxide demand after prechlorination. On the other hand, it would be very desirable to reduce the chlorine dioxide demand because it is much more expensive than chlorine. Thus, the effect of prechlorination upon the chlorine dioxide

demand is very important both from the theoretical and the practical viewpoints. The left-hand graph in Fig. 11 shows the effect of prechlorination by chlorine on the chlorine dioxide demand in the presence of 50 ppm. peptone. The peptone was partially and completely chlorinated by using 7 ppm. and 14 ppm. chlorine, respectively, with one hour's contact; the 14-ppm. chlorine dosage gave a break-point with 50 ppm. peptone, as illustrated in the earlier portion of this paper.

The ortho-tolidine-arsenite values were used in the left-hand graph rather than the ortho-tolidine or potassium iodide values because both of the latter indicate a large chlorine residual in the presence of 50 ppm. peptone. When more chlorine dioxide is added and measured by the same technique, both chlorine and chlorine dioxide are indicated. The ortho-tolidine-arsenite chlorine residual, however, approaches zero in the presence of this amount of peptone, as previously shown.

The results indicate that, by partially or wholly satisfying the chlorine demand, the chlorine dioxide demand is lessened, the reduction being greater as the chlorine demand approaches completion. The data for the right-hand graph in Fig. 11 was obtained from ammonium chloride mixtures of chlorine and chlorine dioxide. The break-point dosage occurred with the addition of 6.0 ppm. chlorine in this particular instance, also as shown previously. Though it has been found that chlorine dioxide does not react with the ammonium ion, these data indicate that some chlorine dioxide is reduced by derived ammonia, such as chloramine. The chlorine dioxide demand is a maximum when chloramines are highest, less chlorine dioxide being reduced at every other point. It appears that as soon as the ammonia has reacted with chlorine, the chlorine dioxide is capable of entering into a reaction with the derived ammonia. It seems logical to conclude from these data that: (1) when chlorine dioxide can react directly, prechlorination will reduce the chlorine dioxide demand; (2) when chlorine dioxide cannot react with a substance by itself, such as ammonia, chlorine may transform the material to some new form that will react with the chlorine dioxide; and (3) if the chlorine reaction is carried to completion, as at the break-point with ammonia, the chlorine dioxide demand approaches zero.

Bactericidal Properties

The data presented in this paper indicate that chlorine dioxide is definitely slower than chlorine in its reactivity with many reductants, and that its redox potential is very slightly lower. The authors have previously shown, however, that chlorine dioxide is more effective than chlorine or that it requires a lower residual than chlorine in killing cultures of poliomyelitis virus (7) and *Esch. coli* (8). Unpublished data indicate that the greater effectiveness of chlorine dioxide against bacteria is also true for spores. This more effective bactericidal action of chlorine dioxide might be due to the fact that it fails to react as readily with contaminants. If so, as the concentration of contaminants is decreased, the relative effectiveness of the chlorine dioxide in comparison with chlorine should decrease. However, the chlorine dioxide requires less and less residual and becomes relatively more effective as the concentration of contaminants decreases. As shown previously, chlorine dioxide reacts with

the large colloidal molecule of peptone in an amount that follows the laws of adsorption on the molecule. Similarly, bacterial cells provide surfaces upon which the chlorine dioxide can be adsorbed. This adsorption phenomenon thereby concentrates the chlorine dioxide around the bacterial cell, where it can be most effective. The chlorine dioxide, once concentrated at the cell surface, can penetrate the cell or change its redox potential so as to destroy those labile enzymes containing sulfhydryl groups (20). This provides an explanation for the increased effectiveness of chlorine dioxide with the decreasing concentration of other colloidal substances which might compete for adsorption of the bactericide (8).

Phenol Tastes and Odors

Several interesting observations have been made on the tastes and odors in solutions used in tracing the reaction between the phenol and the chlorine or chlorine dioxide (*see* Fig. 10). The addition of chlorine dioxide or more chlorine to a reacted phenol-chlorine mixture containing "chlorphenol" destroys the taste and odor of the chlorphenol.

In studying the reaction between phenol and chlorine dioxide, it was noticed that at high concentrations of phenol (5 ppm.) some of the flasks developed a quinone taste similar to, but not identical with, chlorphenol. When allowed to remain standing, these flasks developed the color which is characteristic of a conjugated quinone but lost their taste. The reaction product between phenol and chlorine was stable for at least 72 hours; no conjugated quinone color developed and the taste remained. On the other hand, the chlorphenol is similar to quinone in taste, in oxidizing capacity toward iodide and in reduction capacity toward additional chlorine. It appears, therefore, that chlorine dioxide may develop quinone from phenol slowly and that the quinone conjugates as it is formed. Thus, although the chlorine dioxide in low concentrations forms a bad-tasting compound—quinone—the compound does not happen to be stable enough or present long enough to cause trouble. This possibly explains the failure of chlorine dioxide to produce a noticeable taste in the presence of phenol. It has been shown by the authors (15) that the chlorphenol taste is removed by oxidation with either chlorine dioxide or chlorine.

Summary

The expanding use of chlorine dioxide in water treatment (2, 3) calls for a proper fundamental understanding of the characteristics and reactivity of this compound. It is hoped that the data included in this paper will contribute to that end. The results obtained from these studies show that:

1. Chlorine dioxide can be obtained in pure solution for laboratory use by adding a weak solution of sulfuric acid to a sodium chlorite solution and then sweeping the gas into distilled water by a stream of air. This produces an un-ionized and highly colored solution.

2. The gaseous solution keeps readily at refrigerator temperatures. At room temperatures it decomposes gradually to a colorless solution. If an unbuffered alkali is added to raise the pH above 7.0, decomposition takes place, the pH decreases quite rapidly and the full oxidation capacity is reduced.

3. In pure solutions, such as in stock solutions made up in distilled water, chlorine dioxide may be measured by the same techniques used for chlorine residuals but with some modifications.

By the starch-iodide method, 1 mole of chlorine dioxide will liberate 5 moles of iodine from iodide at pH 1.5 or less. As the pH rises, 1 mole of chlorine dioxide liberates less iodine, until at pH 7.5 to 8.0 only 1 mole of iodine is liberated per mole of chlorine dioxide.

At pH 1.5 to 2.2, 1 mole of chlorine dioxide in pure solution develops color from ortho-tolidine equivalent to 1 mole of chlorine. This value represents one-fifth of the total oxidation capacity of the chlorine dioxide as measured by acid iodide titration at pH 1.5 or less. At pH values lower than 1.5, the excess acid reacts with the chlorite ion, which is the by-product of the first color development, to produce more chlorine dioxide and thus more ortho-tolidine color. The amount of extra color developed depends on the quantity of excess acid.

In the presence of reacting materials, the acid iodide method, at a pH of less than 1.5, measures unreacted chlorine dioxide, chlorite ions and other reduced ions resulting from the chlorine dioxide reaction. Hence, the 1:5 relationship which is demonstrated in pure solutions, such as stock solutions, does not hold but will vary with the reaction products formed.

4. Chlorine dioxide demands may be evaluated by either the acid iodide or ortho-tolidine tests but the results must be properly interpreted. When acid iodide is used, the demand is a measure of the reduction of chlorine dioxide to by-products below the potential of iodide. The principal by-product is the chlorite ion. When standard ortho-tolidine is used, the demand measures that portion of the chlorine dioxide which has lost one electron plus any reaction product which may oxidize ortho-tolidine.

5. Studies on the comparative reaction characteristics of chlorine and chlorine dioxide with certain typical materials, such as ammonia, urea, peptone and glucose, show that, in general, the reactivity of chlorine dioxide with these materials is not greater and is usually less than the reactivity of chlorine with the same substances. Chlorine reacts readily with ammonia, while chlorine dioxide does not. Both chlorine and chlorine dioxide react with phenol. Chlorine reacts readily with peptone, while chlorine dioxide reacts only to a limited extent. Neither chlorine nor chlorine dioxide reacts readily with urea, glucose or alcohol. With substances such as phenol, the reactivity of chlorine dioxide is less affected by pH than is that of chlorine.

6. Studies of eight different water samples of varying degrees of organic pollution indicate very little variation in the chlorine dioxide demands of the natural waters, while the chlorine demands vary widely. In almost every sample the chlorine dioxide demand was less than the chlorine demand. This was especially true with high chlorine demand waters.

7. Toward either iodide or ortho-tolidine, chlorine dioxide shows two distinct oxidizing capacities, representing a two-stage breakdown to, first, the chlorite ion and, second, the re-

duction of the chlorite. The second step takes place only at very low pH values.

8. Free (uncombined) chlorine dioxide, like chlorine itself, may be measured by the ortho-tolidine-arsenite test, provided relationships are obtained between the ortho-tolidine and the ortho-tolidine-arsenite values which are comparable to the relationships in standard or known solutions of chlorine dioxide.

9. The chlorine dioxide demand of organic materials such as peptone follows the laws of adsorption rather than those of chemical reaction, indicating that the amount of chlorine dioxide reacting with such substances at least passes through the adsorption phase. All evidence seems to indicate that chlorine dioxide is less reactive than chlorine with many organic substances in low concentrations.

10. It is indicated that, for materials with which chlorine dioxide reacts directly, prechlorination will reduce the chlorine dioxide demand. When chlorine dioxide cannot react with a substance by itself, such as ammonia, chlorine may transform the material to a new form which will react with chlorine dioxide. If the substance is carried to complete reaction, as at the ammonia break-point, the chlorine dioxide demand approaches zero.

11. Evidence suggests that the bactericidal or sporecidal effectiveness of chlorine dioxide is due to its concentration, by adsorption, on the cell wall.

12. The failure of chlorine dioxide in low concentrations to produce a noticeable taste with phenol is due to either the conjugation or oxidation of the by-product of the phenol-chlorine dioxide reaction, depending on the ratio of the two reactants. The removal of the chlorphenol taste by chlorine dioxide is the result of oxidation.

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Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **39**:473 (May '47) indicates volume 39, page 473, issue dated May 1947. If the publication is paged by the issue, **39**:5:1 (May '47) indicates volume 39, number 5, page 1, issue dated May 1947. Abbreviations following an abstract indicate that it was taken, by permission, from one of the following periodicals: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; Corr.—Corrosion; I.M.—Institute of Metals (British); P.H.E.A.—Public Health Engineering Abstracts; S.W.J.—Sewage Works Journal; W.P.R.—Water Pollution Research (British).*

FOREIGN WATER SUPPLIES—GENERAL

Future Organization and Development of Water Supplies in Austria. STEINWENDER. Gas, Wasser, Wärme (Austria) 1:289 (Dec. '47). Organization, consisting of experienced technical men, needed to develop, construct and supervise all public surface and well water supplies, including industrial water and fire protection. Charges should be uniform, and expansion provided by state on the basis of extra charges. Proper and extensive laws should be enacted. Plans should be made on large scale, without considering municipal, provincial or even state borders; plans should be made for great many years hence. In general, gravity flows should be considered and all potable supplies should be correlated with power and agricultural needs.—*Willem Rudolfs.*

Sterilization of [Belg.] Domestic and Industrial Waste Waters With Chlorine. A. ALBERTZ. L'Eau (Fr.) **2**:17 (Jan. '48). Sterilization of water has not received sufficient attention in Belgium. Prevention of odor and septicity, treatment of sewage and effluents discussed and modern methods described. —*Willem Rudolfs.*

Operation of Water Purification Plants [Brazil]. ALTINO NUNES PIMENTA.R.A.E.; Bol. da Repart. de Aguas e Esgotos (Brazil) **9**:21 (Jan. '47). Paper, presented at First Inter-American Conference of San. Engrs., Rio de Janeiro, '46, deals with importance of pure water, impurities found in water, treatment methods, and chems. used. Special chapters on handling of alum, lime, mixing, flocculation, settling, sand filters, sterilization with chlorine and with calcium hypochlorite. Also describes water works of São Paulo, Brazil. Three stations: Santo Amaro, Cotia, and Rio Claro each pump 23 mgd. and treat water with rapid sand filters and chlorine. Fourth station, Cantareira, pumps 9.5 mgd. and chlorinates water. Addnl. station of 11 mgd. under constr. at Cabucu. Special course set up to instruct plant operators. Operators from other Brazilian plants have also taken course. Lab. control based on Standard Methods of Am. Public Health Assn.—*P.H.E.A.*

Notes on Water Supplies in Denmark and Sweden. F. A. LIEFRINCK. Water (Neth.) **32**:71 ('48). Discussion of sources and treatment of water in number of Danish and Swedish cities.—*Willem Rudolfs.*

The Water Supply for Nice [Fr.]. H. LEBOUT. L'Eau (Fr.) **35**:39 (Mar. '48). City consumes about 17 mgd. obtained from Sainte-Thècle (¼) and Vésubie Rivers. Turbid and polluted water is sand filtered and sterilized with ozone. Bacteriological examination of 1087 samples showed complete absence of *Esch. coli;* total bacteria counts varied from 5 to 15 per ml.—*Willem Rudolfs.*

A Contribution to the Variations of Ground Water Levels in the Center of Berlin Based on 65 Years of Observations (1870 to 1935). FRIEDRICH NÖTHLICH. Gas- u. Wasser. (Ger.) **89**:4:111 ('48). Berlin located over old valley, now filled with alluvial sands and gravels. With average rainfall of 23", considered that yearly infiltration on 25 sq.mi. of center of Berlin would be 1030 mil.gal., but this is reduced by buildings, pavements and storm sewers to only 106 mil.gal. Since 1870 well observations made on 15 wells on

every working day. These data averaged for each month and shown in graphic form. All curves show trend of recession, with '35 levels of from 5′ to 19′ lower than in 1870. Variations in levels claimed to be due to variation in rainfall and pumpage, but recession said to be caused by reduction of infiltration. No data on pumpage or sea level elevations given. —*Max Suter.*

A Countrywide Water Supply for Wurttemberg [Ger.] From Lake Constance. GUSTAVE TROSSBACH. Gas- u. Wasser. (Ger.) **88**:6:167 ('47). Advantages and disadvantages of use of ground and surface water discussed. It is claimed that from hygienic standpoint and for general use surface water preferable. Lake Constance is studied as it may serve as surface supply for whole state of Wurttemberg. This lake, fed from mountainous watershed of 4380 sq.mi., has surface of 207 sq.mi. and capacity of 39,200,000 acre-ft. Quality of water discussed at length and compared with other lake waters. It is shown that water of L. Constance is clear, rich in oxygen to bottom, constantly cold below a depth of 60′, has average hardness of 120 ppm., and is poor in food material with correspondingly small organic life. All these factors make this water suitable for direct use as public supply, which is already being done by many communities. For sake of safety, all sewage discharges into lake should have complete treatment and water taken for public supplies should be either filtered or chlorinated. Such water could be distributed over whole state of Wurttemberg.—*Max Suter.*

Present Problems of a Water Works in a Small Town [Ger.]. AUGUST AURICH. Gas- u. Wasser. (Ger.) **88**:5:155 ('47). Example of Rosenheim (about 30 mi. southeast of Munich) is used. In last 10 yr. population grew from 23,000 to 35,000, water consumption increased 70% and highest hourly use doubled. With 10% of distribution system damaged and lack of labor and materials, supply can be maintained only by improvised patchwork and methods such as: connection with neighboring public supplies, construction of additional wells within city, complete metering and maintenance of meters, reduction of distribution system losses and waste.—*Max Suter.*

Long Distance Water Supply From the Ecker Dam [Ger.]. WILHELM WIEDERHOLD. Gas- u. Wasser. (Ger.) **88**:6:161 ('47). Description of water supply for several communities along 50-mi. pipeline north of Harz Mountains in Germany. Dam 185′ high was built on uninhabited, nearly completely forested watershed of 7.2 sq.mi., with storage capacity of 10,000 acre-ft. Water is soft but slightly acid and colored by humus products from upland swamps. Water from dam passes first through small hydroelectric plant. Half of its output is used at this plant and the adjacent filter plant of 9.5-mgd. capacity. Treatment includes alum coagulation, acidity removal with soda ash and lime, filtration and chlorination. Large storage bins are provided for chemicals; bins storing powdered materials have ceramic filter floors permitting use of compressed air to loosen up storage piles. Steel pipeline is of 24″ and 20″ diameter, with 3 pressure zones. There are storage tanks at each community supplied.—*Max Suter.*

Water Supply in 1947 [Gt. Br.]. ANON. Surveyor (Br.) **107**:93 (Feb. 13, '48). There was steady and widespread activity in planning future action. Quantity of work approved was in excess of previous year's output. Underground water basins restricted included upper part of Lee R. basin, northwest Home Counties area and Lee Valley area. Applications for grants under Rural Water Supplies and Sewerage Act of '44 were announced in Nov. for 547 schemes; 133 provisionally approved; 43 finally approved. Total costs of schemes submitted, provisionally approved, authorized, and submitted for grant on completion: £15,960,357, £7,300,533, £522,000, and £6640, respectively. Up to July Secretary of State for Scotland had offered Scottish local authorities grants totaling £1,148,663 towards water supply and drainage schemes in rural areas. Good progress had been made, by August, in Northern Ireland with designs and contracts for trunk mains for smaller towns, scattered villages and irrigation use. Water has been calculated at 35 gal. (Imp.) per head in rural areas and 40 in towns. Bill empowers Ministers of Health and of Agriculture and Fisheries to establish river boards covering land drainage, protection of fisheries and prevention of river pollution. White Paper on which bill is based gave number of boards (to be created) as 29. There are now no less than 1600. Important British Standard Specification regarding concrete dams has been issued. Unusual assumptions of stress distribution in design are examined in light of new mathematical method of stress

analysis. New Standard Specification (B.S. 1730:1947) covers type of Portland cement with reduced heat of hydration.—*H. E. Babbitt.*

Metropolitan Water Board [Gt. Br.]. Works in Progress and Constructed During 1947. ANON. The Engr. (Br.) **185**:101 (Jan 23, '48). *Ashford Common:* new filtration works, pumping station and supply mains with output of 90 mgd. Treatment plant includes aeration basins, micro-screens and 32 slow sand filters. *Chingford:* slow progress made on reservoir construction. Capacity will be 3180 mil.gal. upon completion. *Fortis Green:* installation of electrically driven centrifugal pumps as stand-by has been approved. Station capacity will be increased by 13 mgd. *Hadley Road:* triple-expansion pumping engine has been replaced by temporary pumps driven by purchased electric power. Two diesel alternators being installed as stand-by to relieve peak load. *Hampton:* largest works operated by the board. Shortly before war construction was started to increase capacity of works from 55 to 120 mgd. Enginehouse was finished before outbreak of hostilities. Remainder of scheme was seriously delayed during war. Primary filters have been completed, as well as major parts of new conduits. Construction of 11.3-mil.gal. balancing reservoir and erection of screening apparatus nearing completion. *Kempton Park:* installation of two new steam raising plants totaling 30,000 lb. per hr. will be put in hand shortly. Installation of 4 automatic self-cleaning experimental rotary strainers has been completed. Two experimental purification plants, each with 1-mgd. capacity, are being installed. *Lee Bridge:* reconstruction of station is progressing. Engine and pump house for new plant is progressing. *Staines:* King George VI Reservoir has been inaugurated. Main objects of above construction works are additional filtration to cope with increasing demand for water, and storage reservoirs. There is necessity also to replace obsolete steam-driven plants. In general, this is being done by pumps driven by purchased electric power, reinforced by diesel-driven alternators.—*H. E. Babbitt.*

The Water Bill, 1947 [Gt. Br.]. ANON. Wtr. & Wtr. Eng. (Br.) **51**:102 (Mar. '48). Bill brings up to date Water Act of '45 and deals with difficulties preventing full use of act. Main purpose is to overcome difficulties that hinder formation of new undertakings and to combine existing undertakings into joint boards.—*H. E. Babbitt.*

A Flooded Water Works. The Lee Valley [Gt. Br.] Inundation. ANON. Surveyor (Br.) **106**:521 (Oct. 3, '47). Thaw commenced Mar. 10. Floods reached max. heights on nights of March 13–14 and 16–17. On Mar. 15 water began to flow into works which became swamped to depth of 1′ to 3′ by 5.30 A.M. Population of 1,250,000 deprived of water. All pumps stopped before filtered water wells flooded. Sunday, Mar. 16, flood waters receded rapidly and by afternoon 1 pump was working. Morning of Mar. 18 floods again rose rapidly but did not reach works. Level down to normal Mar. 20. Reservoir water again received in Lee Bridge works by Mar. 22. By 3.30 A.M. Mar. 23 all 7 Leyton filter beds were charged. Whole of works completely out of action for 9 days. On night of Mar. 13–14 prechlorination dose raised from 0.3 to 1.5 ppm. and terminal dose raised to leave 0.7-ppm. residual. No detectable chem. deterioration could be discerned, but when bact. results available on Mar. 15, they showed 21 out of 28 samples pold. Instructions issued to boil all water. As soon as flood had subsided filter bed cleaning proceeded. On Mar. 27, when pressures had been restored, almost all sample collectors withdrawn. When supply was interrupted arrangements were made immediately to provide emergency supply by tank wagons. Population of 300,000 to 350,000 supplied by this means.—*H. E. Babbitt.*

The Knockendon Reservoir. Irvine and District Water Board [Gt. Br.]. ANON. Wtr. & Wtr. Eng. (Br.) **51**:25 (Jan. '48). Original water works, construction of which commenced in 1877, comprised impounding reservoir of 81-mil.gal. (Imp.) capacity; 2 slow sand filters at Greenhead Mount, with capacity of 0.24 mgd. (Imp.); service reservoir with capacity of 196,500 gal. (Imp.); and mains. With completion of Knockendon Res., supply available from 3 reservoirs will be 5 mgd. (Imp.). Additional sources make available 10.5 mgd. (Imp.). Entire supply is filtered and sterilized at Greenhead where there are 11 slow sand filters with capacity of 1.75 mgd. (Imp.); 26 pressure filters of 3.25 mgd. (Imp.) capacity; and 10 rapid gravity filters of 5.5-mgd. (Imp.) capacity. For yr. '42 total water filtered was 7.5 mgd. (Imp.). Knockendon Res. has storage capacity of 450 mil.gal. (Imp.) with surface area of 7

acres. Dam is 90′ high and 1300′ long; 257,000 cu.yd. of earthwork, 20,000 cu.yd. of puddle clay, 35,000 cu.yd. of stone rubble and 23,500 cu.yd. of concrete were used in construction. Construction was started in '38 and reservoir was inaugurated on Oct. 7. '47.—*H. E. Babbitt.*

Acidity, Chloride Content and Other Chemical Features of Some Irish Fresh Waters. D. A. WEBB. Sci. Proc. Roy. Dublin Soc. (Eire) **24**:24:215 ('47). Fresh waters from various Irish streams, bogs and lakes examd. for pH, Na, Cl and Ca, primarily from biol. standpoint. In general, waters neutral except for strongly acid peat bogs. Na and Cl content of waters highest near west coast, apparently result of wind-borne sea spray.—*C.A.*

Sanitary Engineering—A Korean Episode. PHILIP Z. KIRPICH. Eng. News-Rec. **140**:109 (Jan. 22, '47). After entrance of U.S. occupation forces, san. engrs. played dramatic role in clean-up of Pusan, third largest city in Korea. Combating cholera outbreak called for unusual precautions in connection with water supply and waste disposal practices. Breakdown of existing san. services during war accentuated problem of adapting local methods to bring about and maintain healthful environmental conditions. Public education plus vigorous demonstration led to vast improvement in munic. sanitation.—*Ed.*

Water Supply in Middle East Campaigns. XI. Persia and Iraq. G. L. PAVER & H. DIGBY ROBERTS. Wtr. & Wtr. Eng. (Br.) **51**:136 (Mar. '48). Ground water is obtainable from alluvial lands of Euphrates Valley; yields depend on porosity of particular beds penetrated; quality is highly erratic but is more frequently poor than good. Ground water may be developed in central Persia—area of good precipitation—by drilling into alluvial and detrital deposits which fill typical large structural valleys; boreholes into underlying bedrock are usually dry. Exceptions occur where bedrock is faulted or fissured or contains igneous intrusions. East Persia cannot be considered completely waterless. Factors combine to permit reasonable expectations of ground water in many localities. Little is known about great central salt desert depressions, but in these areas, where precipitation is at minimum, most ground water is likely to be excessively saline. Field surveys might still disclose useful resources of fresh ground water. Geophysical surveys can be of assistance in securing supplies and should be directed toward: (1) establishment of presence and depth of main free water table in valley fill deposits; (2) location in these recent deposits of zones of high porosity formation at water-table level; (3) mapping of boundaries between subsurface alluvial deposits and bedrock contact, thereby assisting in locating favorable sites near side of valleys when so required; (4) location of faults and dikes in bedrock, and (5) location of high porosity zones in alluvial deposits of Euphrates Valley.—*H. E. Babbitt.*

[Neth.] Frost Experiences (Winter 1946-47)—Advisory Committee Report. Water (Neth.) **31**:256 (Dec. 25, '47); 32:2 (Jan. 8 '48). One of the coldest winters since 1700, although coldest average day temperature was only about 10°F. Coldest raw water treated was about 32°F; 40% of main lines were frozen; breaks were numerous. Pipes broke usually 3′–4′ from fire hydrants. Asbestos-cement lines were more subject to breakage than iron pipe. Service lines frozen 23%, mostly at crossing of walls of homes; many instances of frozen lines were not reported.—*Willem Rudolfs.*

Future Water Supply for the Hague [Neth.]—Combination Lek River-Dunes Plan. A. J. GURCK. Water (Neth.) **32**:42,56 (Mar. 4, 18, '48). Type of water in river is not suitable for use during entire year and must be supplemented by dune water. Plan provides for settling and prefiltration of river water, for transporting it to pumping station and mixing with dune water. Mixture is to be treated by rapid sand filters; chlorination and activated carbon treatment to be given when required. Cost is estimated as 7,000,000 guilders, calculated on basis of 1939 costs.—*Willem Rudolfs.*

A Spectrographic Study of the Elemental Composition of Medicinal Waters of the Spanish Peninsula. I. JUAN MANUEL LOPEZ DE AZCONA. Notas y Commun. Inst. Geol. y Minero España (Spain) **17**:3 ('47). Tables are given showing approximate concentration of Al, Ba, Be, Co, Cr, Cu, Fe, Ga, Ge, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Si, Sn, Sr, Ti, V and Zr in 187 water residues. Origins of the samples are shown on map.—*C.A.*

The Waters of the Spring Los Hervidores de Cofrentes [Spain]. TOMÁS ALCOBER & ANTONIO GARRIGUES. Med. Españ. (Spain)

17:446 ('47). Description of water of bicarbonate-sulfate type and its indications.—*C.A.*

Observations on the Bosphorus [Turkey]. III. The Degree of Turbulence. PHILIP ULLYOTT & ORHAN ILGAZ. Rev. Faculte Sci. Univ. Istanbul (Turkey) **11**:107 ('46). When Bosphorus water consists of mixt. of 2 homogeneous waters (high-salinity bottom water from Sea of Marmora and low-salinity surface water from Black Sea) possible to evaluate turbulence diffusion coeff. This varied from 1 to 200 sq.cm./sec. depending on meteorological conditions.—*C.A.*

The Thermal Springs of Erzurum [Turkey]. NÜZHET SAKIR DIRISU. Bull. Faculté Méd. Ankara (Turkey) **1**:44 ('47). Temp. of 4 thermal springs, 15 km. west of Erzurum, 37–39°C., their water greenish and turbid, contg. 0.53 g. of Na per l., 0.13 Ca, 0.08 Mg, 0.05 Fe, 0.28 Cl, 0.09 SiO_2, 0.51 CO_2, and 1.79 HCO_3. Foam on surface of water inflammable, burning with bluish flame. It contains liq. hydrocarbons. Sulfides and H_2S absent. Radioactivity of water is 10 millimicrocuries.—*C.A.*

Capetown's [Un. S. Afr.] New Water Pipeline. ANON. Wtr. & Wtr. Eng. (Br.) **51**:66 (Feb. '48). Two existing pipelines to Steenbras, 32 mi. away, are inadequate. Third line composed of 168,000′ of 34″-diameter mild steel ½″ thick was contemplated. Local company won contract. About 1 yr. later first pipes were leaving new factory (erected for this purpose). Each pipe is 27′ long and is built up from two plates. Welding is done by submerged arc used in shipbuilding. Field joints are of lead-calked bell-and-spigot type. Pipes are protected against underground corrosion with bituminous lining and coating. Pipeline is taking shape at rate of 1 mi. every 10 days.—*H. E. Babbitt.*

LABORATORY CONTROL METHODS AND APPARATUS

The Significance of, and Methods for, Maintaining Moisture in Bacteriological Culture Media. GEORGE H. CHAPMAN. J. Bact. **53**:504 (Apr. '47). Avg. loss of moisture 0.1 ml. from agar plate surface each day in elec. refrigerator. Resulting dry surface detrimental to bact. growth. Moisture loss greatly reduced by storing plates in metal cylinders and sealing vent hole, also joint between top and bottom sections, preferably with waterproof adhesive tape, or parafilm or rubber band. Seal culture media tubes by covering plug or screw-cap and rim with parafilm.—*Ralph E. Noble.*

Automatic Water Sampler Provides Continuous Sampling. ANON. Niagara Pioneer 13:1 (Spring '47). Circular sample bottle plate in main compartment of sampler, which resembles refrigerator, holds 12 bottles. Plate supported by shaft connected to spring-wound clock. Circular trough, semicircular in cross-section and divided into 12 collecting cups, placed over bottles. Outlet equipped with cap at bottom of each cup fits over mouth of sample bottle. Valve connected to any service line allows small, continuous flow of water through pressure reducer to waste. Pressure reduced to constant 15 psi. on gage. Bleed line from waste line conveys water to trough. Sampling mechanism can be regulated to collect a portion of water every 10, 15 or 60 sec. by use of timing device. Device activates solenoid which opens valve periodically to deliver water to trough. Amt. of water delivered governed by length of stroke initiated by solenoid, in its turn regulated by timer. As bottle plate turns, each section of trough will deliver portion of water every 10, 15 or 60 sec. during a 2-hr. period. After 2 hr., next bottle in position to receive next water sample. Trough, outlet, sample bottles, bottle collars, stoppers and stopper hooks should be flamed before and after collection period.—*Ed.*

Preparing Distilled Water of Good Quality. I. Y. YAVNEL. Farmatsiya. (U.S.S.R.) **8**:2:41 ('45). Closed system described and illustrated in which NH_3-free distd. water obtained by distg. water acidified (to methyl orange) with H_2SO_4.—*C.A.*

Opacimeter: Application in Analysis. R. M. EVANS & G. P. SILBERSTEIN. J. Soc. Motion Picture Engrs., **32**:321 ('39); J. Textile Inst. (Br.), **37**: A119 ('46). In many cases changes in transmission of light through solns. may be used in methods of quant. anal. The "Opacimeter," light-sensitive cell, which is color selective, used to measure decrease

intensity of light transmitted by solns. after addn. of chem. reagent. Instrument may be used when reaction gives rise to clear colored soln. or to ppt. uniformly dispersed.—*W.P.R.*

An Easy Method for Reclaiming Waste Chloroform. P. J. PHILSON. Out of the Spigot. 1-2 (Sept. '45). Chloroform used in erythrosin method of detg. total alky. may be reclaimed. Half-gal. portions of spent chloroform accumulated, decanted free from water and washed by shaking 3 times with distd. water. Addnl. wash with caustic soln. (½ stick in 1 l. of distd. water) given. Separation from wash water then made with separatory funnel and chloroform passed through filter paper moistened with fresh chloroform. Storage of reclaimed product should be in brown bottles after adding 1% by vol. of either 95% or absolute alc. Operation should be carried out in well-ventilated room or hood.—*P.H.E.A.*

Should Agar or Gelatin be Used for the Determination of the Germ Count in Water Analyses? EMILE NOVEL. Mitt. Gebiete Lebensm. Hyg. (Swiss), **38**:376 ('47). Results obtained by using agar and gelatin as nutrient media are compared, and superiority of agar for this purpose is stated.—*C.A.*

Laboratory Control of Water Supplies. H. W. STREETER. Supp. No. 201, Pub. Health Reports, U.S. Govt. Printing Office, Washington 25, D.C. 15 pp. The author shows that production of a safe public water supply is a matter in which many efforts must be coordinated. The experience of the author gives great weight to his remarks. Laboratory control now involves not only sanitation of water supplies but conditioning for special uses, both domestic and industrial, not directly associated with hygienic safety. For over 50 yr. the laboratory has enjoyed expanding use in improving water supplies. Publication in 1905 of the first *Standard Methods for the Examination of Water and Sewage*, of which 8 editions have now been published, gave laboratory methods a solid foundation. Since then research investigations in water treatment and advances in the fields of physics, chemistry, and bacteriology have given information and methods for great progress. Development of drinking water standards by the U.S. Public Health Service and their general adoption by the states have made for continued progress. All of this takes on new significance when ever increasing population and sewage related thereto are remembered. Laboratory control of water quality is applicable to various problems such as protection of watersheds, removal of undesirable constituents (both animate and inanimate) from a water supply, protection of water from pollution, and conditioning of industrial waters. Watershed protection is standard practice for larger cities which must depend on surface supplies. Highly important is a systematic biological examination of each reservoir for organisms which cause tastes and contribute bad odors. By results of such examinations it is possible to forestall "blooms" of undesirable species. The author stresses the need for proper collection and transportation of samples for bacteriological analysis. Control of chlorination requires bacteriological tests. Tests for residual chlorine are required, and control of free residual chlorination may be followed in the laboratory. Many other tests on various problems, even in the research field where extraordinary refinements or techniques may be used, are discussed briefly. All of this indicates that water control is now a matter in which the laboratory man is very important. This is a fine summary which was presented at Inter-American Conference on Sanitary Engineering, Rio de Janeiro, June 11, 1946.—*P.H.E.A.*

INDUSTRIAL WATER SUPPLIES

Industrial Water Supply From Processed Sewage Treatment Plant Effluent at Baltimore, Md. ABEL WOLMAN. Sew. Wks. J. **20**:1:15 (Jan. '48). Plant of Bethlehem Steel Co. outside city limits of Baltimore uses 185 mgd. of water for all purposes. Fresh water from underground sources amts. to 50 mgd. Because this source gradually approaching depletion and proposed plant expansion required more fresh water, addnl. sources investigated. Plant-scale expts. indicated these characteristics of water desirable for steel mfg.: temp. below 75°F.; hardness below 50 ppm.; chlorides below 175 ppm.; pH between 6.8 and 7.0; suspended matter below 25 ppm.; org. content and corrosion potential as low as

possible. Many sources studied but treated effluent of Back River Sewage Treatment Works chosen because: continuous flow almost certain; steel plant within economical distance of treatment plant; qual., after processing, favorable for industrial use; and effluent could be purchased and treated at reasonable cost. Two treatment plants operated by city at Back R.: trickling filters can treat over 125 mgd.; activated sludge plant designed for 20 mgd. Steel company uses all activated sludge plant effluent with no addnl. treatment but chlorination. Trickling filter plant effluent processed at 30-mgd. coagulation-settling plant before entering gravity transmission main to steel plant. Alum and chlorine feed equip. in duplicate. Contract requires city to deliver effluent with pH between 6.5 and 7.8; suspended solids less than 80 ppm.; 5-day B.O.D. less than 80 ppm.; and chlorides less than 175 ppm. High chloride concns. in effluent required survey of city to elim. principal sources of high-chloride wastes. Company pays city approx. $1.33 per mil.gal. of effluent. Cost to company, including effluent, processing and pumping, $17.30 per mil.gal. Processed water at steel plant completely independent of sanitary system. Pipelines and valves distinctively painted and lettered.—*F. J. Maier.*

Treatment of Surface Water Supplies for Pulp and Paper Mills. R. R. ADAMS. Paper Trade J. **125**:24:43 ('47). Treatment of surface water supplies in southeastern U.S. may consist of plain sedimentation or flocculation followed by sedimentation and filtration. —*C.A.*

Water in the Textile Industry. J. JODIN. Tech. l'Eau (Belg.), p. 5 (June '47). Daily water consumption in industry estd. to be 40,000 cu.m. Soapy water from washing contains 9500 kg. grease, 3840 kg. organic matter and 7.080 kg sol. mineral matter per cu.m. Rinsing water should have pH of 7–8. Used water contains dirt and putrefactive bacteria, contributing to problem of purif.—*Willem Rudolfs.*

Requisites of Water and Wetting Agents Used in Washing Passenger Train Cars. G. E. MARTIN, ET AL. Am. Ry. Eng. Assn. Bul. 469, p. 78 (Nov. '47). Type of cleaning material used with mech. washers for railroad passenger cars in most extensive service at present time appears to consist of suitable wetting agent mixed with either H_2CO_4 or $NaHSO_4$. Cleaner applied from 30′ to 160′ in advance of mech. brushing and rinsing, and speed of cars through washer is from 60 to 90 fpm. with water used from 100 to 300 gpm. Type of dirt on cars may require variation in type of cleaner and wetting agent used.—*R. C. Bardwell.*

New Developments in Water Conditioning for Diesel Locomotive Cooling Systems and Steam Generators. M. A. HANSON ET AL. Am. Ry. Eng. Assn. Bul. 469, p. 80 (Nov. '47). Chromates with pH control reported as giving best results in conditioning water for diesel cooling systems. For protection of coils in steam generator, best service appears to have been secured by using demineralized water followed by de-aeration and post treatment for pH control. One railroad reports good results by internal treatment with K_2CO_3 which produces nonadherent sludge and thus avoids trouble with adherent sludge experienced with soda ash or phosphate treatment. Photographs of conditions experienced presented.—*R. C. Bardwell.*

Diesels Present New Watering Problems. E. M. GRIME. Ry. Age **123**:6:78 ('47). Diesel locomotives require water for cooling, and steam must be furnished on passenger trains for heating and air-conditioning units. Water for cooling systems must be scale-free and noncorrosive. Demineralized water with pH adjustment or carefully controlled chemical treatment is desirable. Diesel heating boiler is flash type with one continuous coiled tube which converts about 85% of water into steam at 200 psi. in few minutes. Use of scale-free, noncorrosive water with low dissolved solids is necessary. Demineralizing treatment with pH adjustment usually advisable.—*R. C. Bardwell.*

The Significance of Water in the Plating Room. ZACHARY IRENAS. Metal Finishing. **44**:5:195 ('46). Various kinds of impurities found in water from different sources, and effect of dissolved minerals on electroplating discussed.—*I.M.*

Baths and Showers for Industries. M. MISSA & E. LECLERCK. Tech. l' Eau. (Belg.), p. 24 (Jan. '47). Investigation concerning treatment and vol. of water required for showers for miners. Temp. of water to be provided about 40°C. Vol. used varies from 60–225 l. per person, time required from 6–20 min.—*Willem Rudolfs.*

Industrial Utility of Water in Pennsylvania; Chemical Characteristics of Surface Water 1944 to 1946. Pa. Dept. of Commerce, State Planning Board, Publication 17 (Aug. '47). Recognizing need of industry for adequate and reliable data on chemical quality of water in Pennsylvania streams, study was made to obtain systematic records of chemical characteristics of surface waters throughout state, and to consider factors that affect water quality. Study was divided into number of phases, including low-flow and high-flow studies; daily sampling-station studies; cross-section studies; unit basin studies; and miscellaneous studies. Each of these phases is discussed separately. There is also discussion of source and significance of chemical and physical characteristics of natural waters and of methods of analysis employed. Major part of volume is given over to tabulations of analytical data collected, expressed both as parts per million and as equivalents per million. Copies of this publication are available on request to State Planning Board.—*S.W.J.*

STERILIZATION

Chlorine Dioxide. A Summary of the Development of its Use for Water Works Purposes. ANON. Wtr. & Wtr. Eng. (Br.) **51**:48 (Feb. '48). At ordinary temperature and pressures chlorine dioxide is yellow to red, unpleasant smelling, irritating gas, with vapor density of approximately 2.4. Odor is evident at approximately 14 to 17 ppm. and at 45 ppm. it is irritating. Because of instability it cannot be produced in bulk and stored until wanted, but must be generated at low concentration at point of use and consumed immediately. Chlorine dioxide can be formed by treating sodium chlorite with acid or chlorine as follows:

$$5NaClO_2 + 4HCl = 4ClO_2 + 4NaCl + 2H_2O$$
$$2NaClO_2 + Cl_2 = 2NaCl + 2ClO_2$$

For water works purposes sodium chlorite solution and chlorinated water from chlorinator are fed continuously into reaction chamber. Resulting chlorine dioxide solution is fed into water system. For complete reaction minimum proportion of Cl to $NaClO_2$ should be at least 50% above theoretical. Recommended weight basis is not less than 1:2 and preferably 1:1. Rise in pH will decrease efficiency of reaction. Except in waters with extremely low organic matter, chlorine dioxide is much less effective than chlorine in equivalent concentrations. Efficiency of chlorine dioxide increases as chlorine demand of water decreases. Bactericidal value is not affected by pH value. It hydrolyzes only to limited extent and effect of hydrogen ion is, therefore, of relatively minor importance. It is important to employ prechlorination when dioxide is to be used for control of odors and tastes, and sufficiently far enough ahead of dioxide to have completed its effects. There are indications that small amounts of ClO_2 do have some killing effect over long periods of time. This should prove valuable in distributing systems. When used in polluted water, ClO_2, because it is more reactive than Cl_2, destroys phenols, algae and other contaminants at same time that it attacks bacteria. Hence, disinfection of polluted water requires more ClO_2 than Cl_2. It is more economical to satisfy chlorine demand with Cl_2 and follow by treatment with ClO_2. Main value of ClO_2 is success with which it can be used to combat taste and odor troubles. It possesses oxidizing potential of 2.5 times that of Cl_2, and may always react to produce least readily tasted tri-chlorophenol. (Tabulated data show average amount sodium chlorite used at various plants varying between 2 and 6 lb. per mil.gal., with cost of ClO_2 per mil.gal. from $2 to $10.50.)—*H. E. Babbitt.*

Instantaneous Disinfection of Drinking Water by Ozonation. ALFRED TORRICELLI. Mitt. Gebiete Lebensm. Hyg. (Swiss) **38**:176 ('47). Various methods for disinfection of drinking water are discussed. Comparisons between chlorination and ozonation processes show that latter is decidedly superior. Conditions were established to give optimum results.—*C.A.*

Results of Chlorination of Army Water Supplies. C. C. SPENCER. Pub. Wks. **78**: 9:31 (Sept. '47). Increased possibilities of contamn. of water supplies anticipated during war. These included broken mains, damaged treatment works, hydraulic changes caused by fire-fighting and deliberate contamn. by pathogenic bacteria and poisons. Ordinary lab. control methods provide little protection, principally because of delay in obtaining results, and routine procedures do not reveal all pathogens and poisons. Chlorination appeared to provide best protection in that it was already widely used, would destroy most contams., and changes in residuals would serve

as warning. Although chlorine demands vary widely, army specified min. chlorine residual because of higher water demands, possible changes in distr. systems, unknown factors in new supplies and effect of sudden increases in demand on distr. main deposits. In Nov. '42, army instructed all fixed camps and stations to provide 0.4 ppm. chlorine in all parts of systems. This proved impracticable and in July '43 instructions modified to require 0.4 ppm. after 30-min. contact, except where water obtained from municipalities having satisfactory treatment and control. Communicable diseases among troops carefully compiled and no outbreaks of waterborne disease recorded at army installations in U.S. between '42 and '47. During '42, '43 and '44, Public Health Service reported 10 outbreaks involving 4500 cases in civilian communities caused by inadequate or interrupted chlorination. Of 240,000 samples collected in U.S. posts during '44 and '45 less than 2% reported as nonpotable.—*F. J. Maier.*

Recent Developments in Chlorination. A. E. GRIFFIN & N. S. CHAMBERLIN. J. Pa. Water Works Operators' Assn. **19**:57 (1947). Article consists of a discussion of advances in chlorination since the year 1940. It is now recognized that the term "residual chlorine" is no longer adequate to describe chlorine present in water. Especially where the breakpoint process is being used it is necessary to differentiate between free available and combined available chlorine. Tests developed for this purpose are (1) ortho-tolidine-arsenite test, (2) amperometric titration using sodium arsenite, (3) ortho-tolidine titration method (Jour. A.W.W.A. **39**:209 Mar. '47) and (4) enzymatic method of Stumpf and Green (Jour. A.W.W.A. **38**:1301, Nov. '46). Many erratic results obtained in the past with respect to bacteria kill were undoubtedly due to alternate presence in water of free available chlorine and combined available chlorine. It is now known that free available chlorine will kill practically all types of bacteria within three minutes, practically all types of slime-forming bacteria that accumulate on the interior of pipes, and practically all types of algae. In addition it will improve coagulation in many cases, bleach color, and permit the removal of manganese without an increase in the pH of the water. Although it was reported in 1940 that Ottumwa, Iowa, used 111 ppm. chlorine in order to exceed the break-point and produce a free available chlorine residual, surveys show that average requirement for fifteen widely scattered plants varies from 2 ppm. to 12 ppm. One recently discovered use for chlorine is for the destruction of cyanides in industrial wastes. Other uses for chlorine in industry are discussed. Mention is made of the application of chlorine dioxide and of fluoride to water supplies.—*Kenneth E. Shull.*

The Sterilization of Sewage Effluents by Means of Gaseous Chlorine. J. A. MCLACHLAN & J. R. GAILLARD. 1946 Annual Report of the City Engineer of Johannesburg, pp. 33–47. Object of work was to produce complete sterility of well-oxidized sewage effluent using presumptive test for *Escherichia coli* and total agar count. Complete bact. sterility aimed at with hope that it might result in inactivation of poliomyelitis virus. Variables studied were (1) chlorine dosage 0.2 to 120 ppm.; (2) contact time, 10 min. to 24 hr.; and (3) chlorine demand. *Escherichia coli* tested in 10-ml. portions and plate counts 1-ml. portions. Substrate used sand filter effluent. With 10-min. contact period chlorine doses of 15 to 95 ppm. necessary to destroy *Escherichia coli* and all colony-producing organisms on agar. It requires great deal more chlorine to destroy all growths on agar plates with 1-ml. inoculations than to get negative *Escherichia coli* test in 10-ml. sample. Latter can be accomplished with dosages as low as 5.2 ppm. of chlorine and 10-min. contact time. Concluded that sterility as indicated by negative presumptive test in 10-ml. and negligible plate count on agar with 1-ml. sample may be taken as index of efficiency of chlorination. Choice is between high dosages (100 ppm.) with short contact period (10 min.) and lower dosages with longer contact period (24 hr.). Disadvantage of first is adverse effect of high residuals in effluent on soil or in river, depending on final method of disposal. Second alternative entails cost of large contact tanks. Chlorine demand concept as applied to disinfection of sewage effluent criticized. No indication of breakpoint has been observed with dosages up to 120 ppm.—*Sew. Wks. J.*

A Simpler Apparatus for Water Chlorination. J. GRAF. Gas, Wasser, Wärme (Austria) **2**:11 (Jan. '48). Description of "drip" apparatus consisting of a carboy with chlorine solution, valves, and simple injector.—*Willem Rudolfs.*

An Experiment in Free Chlorination of Public Water Supplies. WILLIAM DEKLEINE & RAYMOND J. FAUST. J. Mich. State Med. Soc. **45**:1055 ('46). A discussion of free chlorination of public water supplies in some Michigan municipalities.—*C.A.*

The Handling of Chlorine. ANON. Wtr. & Wtr. Eng. (Br.) **51**:68 (Feb. '48). Liquid chlorine is clear amber in color, and is approximately 1.5 times as heavy as water. At atmospheric pressure it boils at −30°F. It vaporizes rapidly when exposed to atmosphere. One lb. liquid chlorine forms about 5 cu.ft. of gas; 1 vol. of liquid yields approximately 460 vol. of gas. Hence liquid chlorine break may be very hazardous. Dangerous compounds may be formed when chlorine comes in contact with other gases. In poorly ventilated space containing carbon monoxide phosgene will be formed. In use of chlorine and ammonia care must be taken not to mix gases because of danger of forming highly explosive nitrogen trichloride. Chlorine is neither flammable nor explosive. In presence of moisture it is very corrosive and combines readily with most metals, except "noble" metals. Dry gas becomes corrosive at temperature above 300°F. Compressibility coefficient of liquid chlorine is more than any other liquid element (approximately 0.0118% vol. atmosphere) Temperature-pressure relationship is such that above 156°F. cylinder loaded to legal limits is subjected to pressure sufficient to rupture it. At atmospheric pressure and 32°F. 1 l. of dry gas weighs 3.214 g. One cu.ft. of liquid chlorine weighs 91.64 lb. at 32°F. and 3.65 atmospheres. (U.S. Bureau of Mines Tech. Bull. 248 gives physiological effects of various concentrations of chlorine gas.) Short shallow breathing should be used in atmosphere containing chlorine gas. Symptoms of advanced stages of exposure are retching and vomiting followed by difficult breathing. Death can occur from apparent suffocation. Gas produces no cumulative effects and complete recovery occurs from mild exposure. Repeated exposures to small concentrations have ended with symptoms such as result from heavy concentration. This condition is likely to arise where operators have prejudice against wearing mask. Liquid chlorine in contact with skin or clothing may cause burns. Containers should be stored in upright position in cool, well-ventilated place. Gas should not be withdrawn more than 1.5 lb./hr., otherwise internal temperature is unduly lowered. If constant supply of gas at constant pressure is to be maintained heat must be supplied by increasing room temperature few degrees; not by flame, steam, or radiant heat. Valves on container should be opened slowly and large wrenches not used. Rubber and noble metals are sufficiently resistant to action of wet chlorine to be satisfactory to handle either moist gas or water solutions. Chlorine reacts with grease and oil to form voluminous frothy substances; with petrol and petrol distillates to form solid complex chlorinated hydrocarbons. Condensation in lines should be avoided. Liquefied gas in feed lines will find its way into chlorinators. If line pressure is kept at 40 psi. or less no condensation can occur in lines at room temperature. Chlorine in distilled water at 49.2°F. will form chloralhydrate, commonly referred to as "chlorine ice." Formation may be overcome by placing elec. light under chlorinator. Leakage can be detected by holding open-mouthed bottle containing ammonia beneath probable site. Leaks may be lessened by reducing temperature and by withdrawing gas as quickly as possible. Dry ice is about only material that can be used successfully to cool cylinder enough to stop leak. Probably best method, if gas cannot be drawn off sufficiently rapidly, is to immerse cylinder in large body of flowing water. Ample ventilation should be provided, with exhaust air ducts taking in at floor level and exhausting out of building. Gas masks should be available well outside area of contamination, where they can be found.—*H. E. Babbitt.*

Chlorine Accident in Brooklyn. H. CHASIS, J. A. ZAPP, J. H. BANNON, J. L. WHITTENBERGER, J. HELM, J. J. DOHENY & C. M. MACLEOD. Occupational Med. **4**:2:152 (Aug. '47). After accidental exposure to chlorine gas in June '44, 418 persons were examined at 8 Brooklyn hospitals, and 208 were sufficiently ill to require admission. Cause of accident was leaking cylinder of chlorine which was being conveyed by truck to destination in Brooklyn. When leak was discovered, driver pulled up to side of road, unfortunately only few inches from series of gratings covering ventilating shafts leading from pavement to subway station platform. Ventilation of these stations depends upon movement of trains and varies between inflow and outflow, with periods of no measurable flow. During 17 minutes truck was parked near grating,

casualty-producing concentration of chlorine gas was built up in station, and practically all casualties occurred among people exposed in subway, only 2 exceptions being in store opening on to street and in vehicle which was following immediately behind truck with leaking cylinder. Clinical data in report relate to 133 patients who came under observation of authors in Cumberland Hospital. Of these, 33 showed evidence of moderate or severe poisoning and required hospital care for a period of 1 to 2 weeks. Remainder were discharged within 2 or 3 days. Immediate symptoms consisted of choking, nausea, vomiting, anxiety and syncope and extreme weakness, amounting in some cases to prostration. Dyspnoea and substernal pain were present in 31 of 32 patients who required prolonged hospital care, and in many others who were discharged after 3 days. Cough was present in all cases within 2 hours, and in some cases persisted as long as 15 days. Loss of consciousness occurred in 8 patients, in 1 lasting for over 30 minutes. All those admitted to wards appeared to be acutely ill with marked respiratory distress, half were cyanosed, and all but 5 of 33 were febrile on admission, with temperatures up to 102°F. Respiratory distress usually subsided within 72 hours, responding well in some cases to administration of broncho-dilators such as aminophyllin and epinephrine but only when these were given early. Pulmonary edema developed in 23 patients and basal pneumonia in 14. Sputum examinations showed no specific characteristics and only alteration in blood picture was slight increase (up to 16,000) in total white cell count, with occasional increase in polymorphonuclear leucocytes. Treatment consisted in administration of oxygen at site of accident, conveyance by ambulance to hospital and further oxygenation in accident room and ward. Codein phosphate or sulfate was given by mouth or intramuscularly in doses ranging from 0.03 to 0.12 g. to allay cough. Barbiturates were given for sedation. Oxygen under pressure of 4 to 6 cm. of water appeared to alleviate respiratory distress more quickly than when it was given at atmospheric pressure. Chemotherapy was instituted to prevent development of secondary bacterial infection, 15 patients receiving sulfadiazine, and 7 parenteral penicillin, while 11 patients received no chemotherapy and acted as control group. Incidence of pneumonia was 7 of 22 in combined treated groups and 7 of 11 in untreated group. Sulfadiazine is considered prophylactic of choice as it is effective against both Gram-positive and Gram-negative organisms. Eleven of the patients who were followed up for 16 months after discharge had no residual symptoms attributable to chlorine, but 16 others had anxiety reactions and psychomotor disturbances. There was no evidence of late pulmonary disease. Clinical conditions recorded in this series are expected results of exposure to highly irritant and readily soluble gas. Interesting features are pyrexia in those heavily gassed, and common occurrence and persistence of psychological manifestations. This accident stresses need for careful packing of dangerous gases and liquids and potential danger to general public of these substances while in transit. Obvious safety precaution is that driver should be fully aware of nature of his load.—*B.H.*